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PAPERS IN PRESS FOR FORTHCOMING ISSUES

GEOLOGY OF THE NORTHWESTERN WIND RIVER MOUNTAINS, WYOMING. By C. L. Baker*

Contains colored geologic map of part of Fremont Peak quadrangle, U. S. G. S. topographic sheet as base. Scale, 1″ = 2 miles ($.25 each)

GRAIN-SHAPE FABRICS OF CLASTIC QUARTZ. By Richards A. Rowland

QUARTZ CRYSTAL IN BRAZIL. By W. D. Johnston, Jr., and Robert D. Butler

CAMBRIAN AND EARLY ORDOVICIAN STRATIGRAPHY OF THE LOWER ST. LAWRENCE VALLEY. By Franco Rasetti

COMPETENCY OF MOVING WATER TO TRANSPORT DEBRIS. By Charles Nevin

DATING SEDIMENTATION, VULCANISM, AND OROGENY IN THE BEARTOOTH MOUNTAIN REGION, MONTANA, BY HEAVY MINERALS. By Marcellus H. Stow

*As an innovation, and for a trial period, we shall have available for separate purchase 100 unfolded copies (in tubes, at prices indicated) of colored maps appearing in the Bulletin. Orders will be filled as long as the supply lasts.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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TERTIARY AND QUATERNARY GEOLOGY OF THE LOWER RIO PUERCO AREA, NEW MEXICO

BY HERBERT E. WRIGHT, JR.

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ABSTRACT

The eastern part of the Lower Rio Puerco area is located in the Albuquerque-Belen basin, a subdivision of the Rio Grande depression, which in turn is an extension of the Basin and Range physiographic province. The western part is in the Colorado Plateaus.

The Albuquerque-Belen basin was formed in the late Tertiary by downwarping and downfaulting. Streams eroded the Carboniferous and Mesozoic sedimentary rocks and the early and middle Tertiary volcanic rocks and deposited the sediment in the depression. Contemporary vulcanism produced local basaltic lava flows. The basin deposit and the interbedded basalt constitute the Santa Fe formation. The basin deposit consists of a maximum of 4800 feet of alluvial-fan beds, axial river gravels, and playa beds. The proportion and detailed lithology of these types depended upon the rate of uplift and erosion of the highlands, the rate of subsidence and deposition in the basin, the lithology of the source rocks, and the climate. Study of the horizontal and vertical differences in lithology in the Santa Fe formation reveals the changing physiographic and dynamic relations of the Rio Grande depression and bordering highlands during the late Tertiary. These relations are shown on two paleogeographic maps.

The western border of the Albuquerque-Belen basin is marked by a complex fault zone which was established as a zone of weakness during the early Tertiary warping of the Colorado Plateaus. The late Tertiary Santa Fe basin deposit overlapped this border, but accelerated subsidence of the basin produced faults along the old fault zone, and the Santa Fe formation is now delimited on the west by late- and post-Santa Fe faults which have a maximum displacement of 6300 feet.

The main period of late Santa Fe and post-Santa Fe deformation was followed in the early Pleistocene by a period of crustal stability, during which time the extensive Ortiz erosion surface was developed on the deformed Santa Fe and older formations. This erosion surface was graded to an ancestral Rio Grande 400–500 feet above the present Rio Grande. A paleogeographic map was prepared with restored contours to show the drainage lines on this surface within the Albuquerque-Belen basin and the plateau contry to the west.

Renewed regional deformation, marked locally by small faults, initiated a major stream piracy and the general dissection of the extensive Ortiz surface. Subsequent erosion and regional changes in base level have produced from two to four post-Ortiz

erosion surfaces along the major streams of the Lower Rio Puerco area, with gradients 250–300, 175–200, 100–150, and 50–75 feet respectively above those of the present streams.

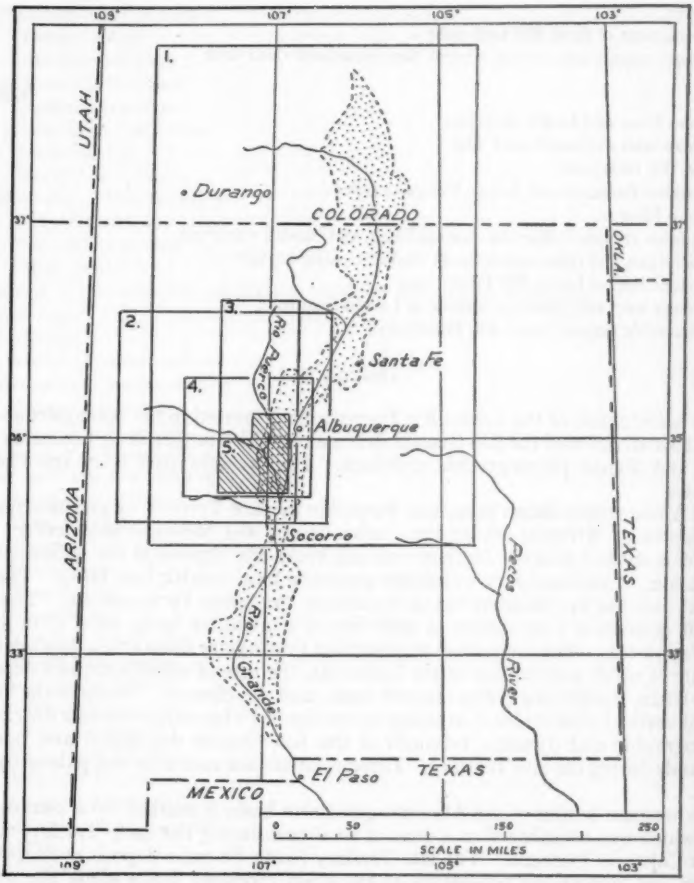

FIGURE 1.—*Map of New Mexico*

Areas covered by maps in this paper are outlined. Stippled pattern shows Rio Grande depression.

1. Physiographic provinces of north-central New Mexico (Fig. 2).
2. Paleogeographic map for Ortiz time (Fig. 12).
3. Fault pattern of western border of Albuquerque-Belen basin (Fig. 9).
4. Paleogeographic maps for Santa Fe time (Figs. 4, 5).
5. Lower Rio Puerco area (Plates 8, 10).

All the erosion surfaces in the Lower Rio Puerco area are covered and in part protected by stream gravel, caliche, wind-blown sand, travertine, or basaltic lava flows. The geomorphic map of the area shows the distribution of these different covers as well as the distribution of the remnants of the surfaces themselves.

INTRODUCTION

PRELIMINARY STATEMENTS

The present study primarily concerns the history of the Albuquerque-Belen basin and the origin, deformation, and dissection of the basin deposit—the Santa Fe formation. This basin is a portion of the Rio Grande depression; its relation to the physiographic provinces of New Mexico is shown in Figures 1 and 2. It is bordered on the north by the Jemez Mountains, on the east by the Sandia, Manzano, and Los Pinos fault-block mountains, on the south by the Socorro Mountains and on the west by the high mesas of the Colorado Plateaus. The eastern portion of the basin is drained by the through-flowing Rio Grande. Its tributary the Rio Puerco drains the western portion. Between the two river valleys is a long narrow erosion remnant, the Llano de Albuquerque.

The Lower Rio Puerco area itself includes the western portion of the Albuquerque-Belen basin and the eastern border of the Colorado Plateaus. It has a total area of about 2000 square miles in Valencia, Bernalillo, Sandoval, and Socorro Counties. The elevation ranges from almost 7500 feet on Mesa Pato to about 4800 feet on the Rio Grande (Fig. 3).

BACKGROUND OF THE STUDY

Comments on the stratigraphy and structure of the Tertiary deposits of the Rio Grande depression may be found in the reports of the early geological surveys in the Southwest (Hayden, 1869; Cope, 1877; Gilbert, 1875) and in scattered papers a generation later (Herrick, 1898a, 1898b, 1900; Johnson, 1903; Lee, 1907; Bryan, 1909). The pre-Tertiary rocks of the highland areas adjacent to the Rio Grande depression have been most completely studied by Darton (1928), whose reconnaissance geologic map of parts of Valencia and Socorro Counties was of great value in the present study. The pre-Tertiary rocks of the northwestern part of the Lower Rio Puerco area were mapped by Hunt (1936, 1938); therefore in this section of the area the writer mapped only the Santa Fe formation.

During the last few years Bryan and coworkers have undertaken a systematic study of the Santa Fe formation and the Rio Grande depression, and have accumulated many data concerning the origin and deformation of basin deposits. In Figure 2 the areas of recent detailed study are outlined.

The present paper is the result of the continuation of this program with the following aims: (1) to extend the stratigraphic subdivision of the Santa Fe formation as established by Bryan and McCann (1937) in the northern portion of the Llano de Albuquerque southward along the western portion of the Albuquerque-Belen basin to the San Acacia area of Denny (1940a); (2) to study the western margin of the basin over an extended distance in order to supply new data concerning the mode of subsidence of the Rio Grande depression during and after the deposition of the Santa Fe formation; (3) to correlate the remnants of ancient erosion surfaces in the Albuquerque-Belen basin and in the plateau area to the west in order to elucidate the physiographic and dynamic development of the region during the Quaternary.

These objectives have been largely realized. The Santa Fe formation in the Lower Rio Puerco area has recognizable lower, middle, and upper portions represent-

ing somewhat differing late Tertiary geographies. Uplift of the bordering highlands and subsidence of the basin during Santa Fe time has been proved. The post-Santa Fe erosion period represented by the Ortiz surface has been more closely defined, and the intervention of tectonic movements in the Pleistocene more firmly established.

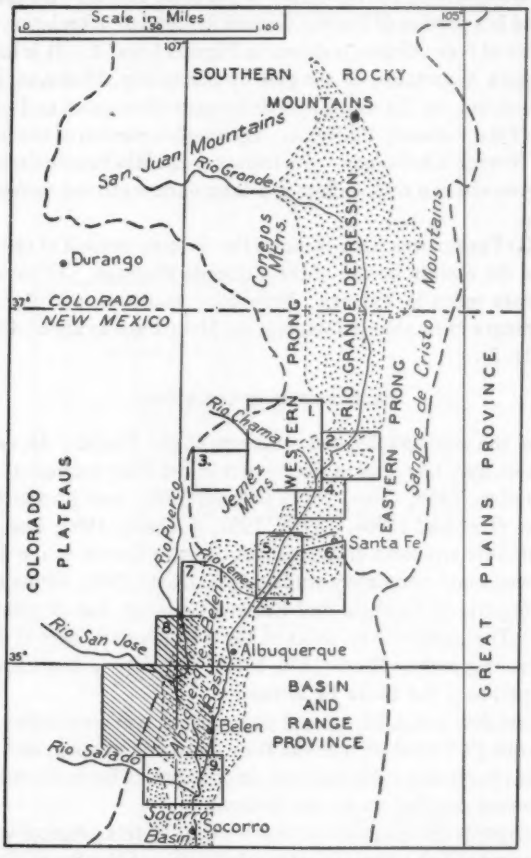

FIGURE 2.—*Map of north-central New Mexico and south-central Colorado*

Boundaries of physiographic provinces and locations of areas of recent detailed study are outlined. (1) Abiquiu quadrangle, Smith, 1938; (2) Picuris area, Cabot, 1938; (3) Northern Jemez Mountains, Church and Hack, 1939; (4) Espanola Valley, Denny, 1940b; (5) Santo Domingo Valley, Bryan and Upson, unpublished; (6) Galisteo-Tonque area, Stearns, unpublished; (7) Northern Ceja area, Bryan and McCann, 1937, 1938; (8) Lower Rio Puerco area; (9) San Acacia area, Denny, 1940a, 1941.

METHODS OF MAPPING

The base maps used were planimetric drainage maps (scale 1:62,500) compiled from aerial photographs by the Soil Conservation Service. Aerial mosaics on the same scale and contact prints on twice the scale (1:31,250) were found indispensable for location and correlation.

Reconnaissance topographic maps by Darton and others were available for most of the area covered by the map of the restored Ortiz erosion surface (Fig. 12), and they were useful for rough correlation of the physiographic surfaces. Only the Albuquer-

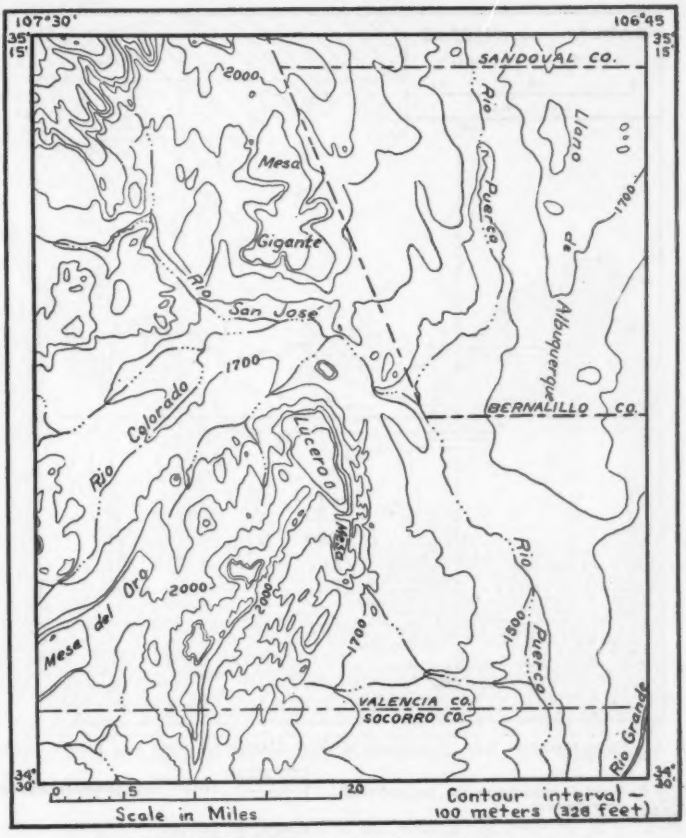

FIGURE 3.—*Topographic map of the Lower Rio Puerco area*
(From Darton, Topographic Map of New Mexico, 1925.)

que sheet (scale 1:31,250) was precise enough for study of many of the smaller features. Over much of the area, therefore, a Paulin barometer and a hand level were used. Although the daily pressure variation in this region in the summer is .06–.15 inch, or the equivalent of 60–150 feet, the average error of the corrected barometer readings is believed to be less than 30 feet.

ACKNOWLEDGMENTS

The writer is primarily indebted to Professor Kirk Bryan of Harvard University, who planned and guided the project. Many of the ideas herewith presented were inspired by discussions with him. Professors M. P. Billings and E. S. Larsen, Jr., of

Harvard visited the writer in the field and have helped in structural and petrographic problems. Professor P. E. Raymond and Dr. Frank Whitmore made the fossil determinations. Mr. Edward A. Schmitz drafted Plates 8, 9, and 10 and Figure 12;

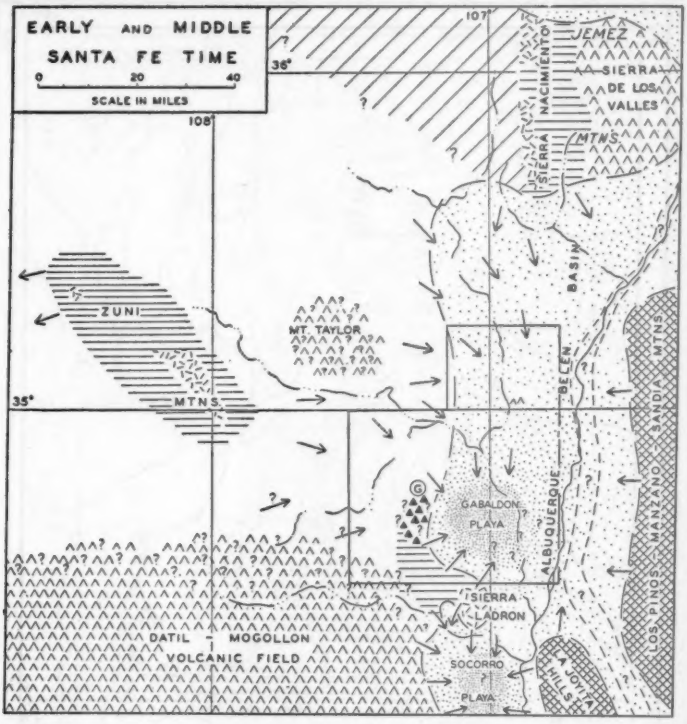

FIGURE 4.—*Paleogeographic map of west-central New Mexico for early and middle Santa Fe time*

Santa Fe formation: playa, fan, and axial river deposits.

Basalt interbedded in Santa Fe formation.

Mid-Tertiary non basaltic volcanics.

Uppermost Cretaceous and Eocene formations which contain pebbles.

Cretaceous and Jurassic formations.

Triassic and Carboniferous formations.

Pre-Cambrian rocks.

Pre-Santa Fe rocks, undifferentiated.

Direction of stream flow.

Locality described in text.

Boundary of Rio Grande depression.

Mr. Donald Bailey drafted Figures 4, 5, and 8. Mrs. Helena Barden and Mr. John C. Rabbitt helped with the manuscript. The aerial photographs and maps of the Soil Conservation Service were made available through the courtesy of Mr. A. C.

Blakey, Chief of the Cartographic Division, Rio Grande District. Dr. C. V. Theis of the U. S. Geological Survey arranged for the analyses of the spring waters.

Expenses for the field work were largely met by grants from the Whitney Fund of Harvard University.

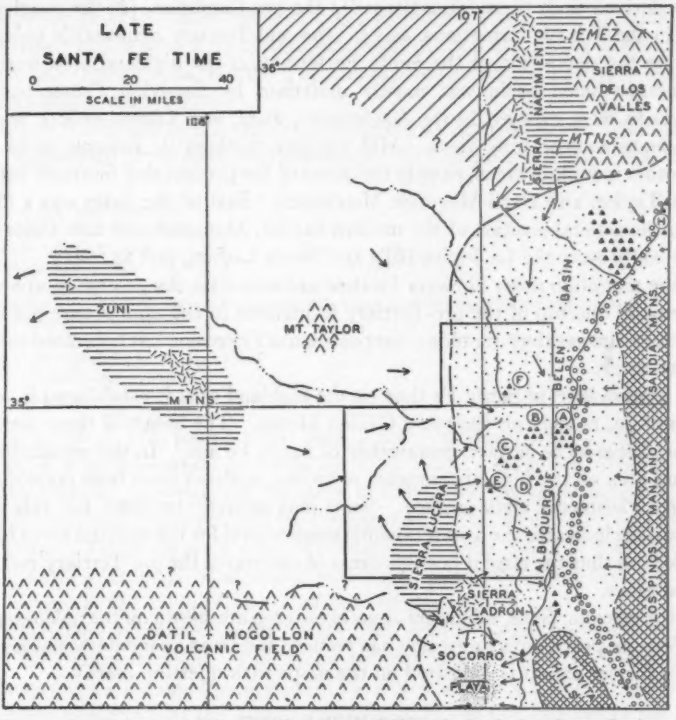

FIGURE 5.—*Paleogeographic map of west-central New Mexico for late Santa Fe time* *See* legend for Figure 4.

The writer was ably assisted in the field in the summer of 1940 by J. W. Dow and R. C. Bryan, and in the summer of 1941 by G. J. Lyons. He is also indebted to a number of residents of the area for numerous courtesies, notably Mr. and Mrs. George S. Bryan and Mr. M. P. Trossello of Albuquerque and to Mr. and Mrs. Malcolm Major of Los Lunas.

STRATIGRAPHY OF THE PRE-SANTA FE ROCKS

INTRODUCTION

The streams which deposited the Santa Fe formation in the Albuquerque-Belen basin derived their sediment from the pre-Santa Fe rocks of the bordering highlands. Much of the material in the Santa Fe formation may be traced directly to the particular highland from which it was derived, thus revealing the geography of the Albuquerque-Belen basin and bordering highlands in Santa Fe time.

Two paleogeographic maps of northwestern New Mexico have been prepared to show the major areas of outcrop of the source rocks and the inferred drainage directions for portions of Santa Fe time (Figs. 4 and 5). The most significant units of the source rock are those which supplied to the Santa Fe formation distinctive pebbles mostly derived from three formations: (1) the pre-Cambrian, (2) the conglomeratic layers in the Triassic formations, and (3) the mid-Tertiary nonbasaltic volcanics.

During the deposition of the Santa Fe formation the highland area west of the Albuquerque-Belen basin was mostly underlain by flat-lying Cretaceous rocks. Older rocks were exposed in the Nacimiento, Zuñi, and Lucero uplifts, which are still mountainous or hilly areas. Mid-Tertiary nonbasaltic volcanic rocks formed three other mountain areas, namely the areas of the present-day Sierra de los Valles, Mount Taylor, and Datil-Mogollon Mountains. East of the basin was a highland area in the general position of the modern Sandia, Manzano, and Los Piños ranges. To the south were the La Joyita Hills and Sierra Ladron, just as today.

All the mountain areas of Santa Fe time are shown on the paleogeographic maps. The areas of outcrop of the pre-Tertiary formations in the uplifts were not so large in Santa Fe time as they are today, for post-Santa Fe erosion has truncated the uplifts at lower levels.

The erosion level of Santa Fe time on the highland area is established in only one small section, namely on Pato and Gallina Mesas. The basalt of these mesas rests on a pre-Pleistocene surface presumably of Santa Fe age. In the remainder of the highland area all the highest remnants of erosion surfaces have been correlated with the early Pleistocene Ortiz surface. Some may actually be older, but this restored Ortiz surface indicates the lowest possible erosion level for the uplifted areas for Santa Fe time, and thus the largest possible areas of outcrop of the pre-Tertiary rocks in the uplifted areas.

For the volcanic fields, minimum areas of outcrop are shown on the paleogeographic maps because post-Santa Fe erosion has reduced the areas an indeterminable amount. Possible former extent is indicated on the maps with question marks.

PRE-CAMBRIAN ROCKS

The pre-Cambrian cores of the Nacimiento and Zuñi Mountains consist of massive red granite gneiss, pegmatite, quartzite, and schist. These rock types supplied pebbles to the Santa Fe formation in the Lower Rio Puerco area either directly from pre-Cambrian outcrops or secondarily from conglomerates in Triassic rocks. The well-rounded pebbles of quartzite and quartz from Triassic conglomerates were broken and rerounded before being deposited in the Santa Fe formation.

PENNSYLVANIAN SERIES

Magdalena Limestone.—The Magdalena limestone is exposed in the core of the Lucero anticline from Arroyo Carrizo south (Pl. 8). At least 1000 feet is visible, and the base is not exposed. Most of the formation is made up of thick beds of gray resistant limestone which supports large hogbacks such as Cimarron Mesa. Near the middle of the formation are a few thick beds of coarse quartz sandstone cemented with coarsely crystalline calcium carbonate.

In the Puertecito district west of Sierra Ladron, Wells (1919, p. 11) gives a thickness of 1000 to 1200 feet for the Magdalena limestone. Westward the Magdalena thins (Darton, 1928, p. 133), and it is absent on the Zuñi uplift. On the southwest flank of Sierra Ladron, limestone rests unconformably on the pre-Cambrian rocks (Darton, 1928, p. 111). Here the lowest 125 feet of limestone beds contains Mississippian fossils and is thus a northward extension of the Lake Valley limestone. In the Lower Rio Puerco area, however, all the exposed limestone probably belongs to the Magdalena (Pennsylvanian).

The top of the Magdalena limestone, as exposed on Arroyo Carrizo, consists of 115 feet of interbedded green shale and limestone. The measured section is as follows:

	Feet
Red beds of the Abo formation	top
Green shale and chocolate shale	10
Blue fossiliferous limestone	5
Green shell-conglomerate	1
Blue dense limestone with some interbedded green shale	10
Blue and green thin-bedded shale alternating with 1 to 4 inch layers of hard limestone	60
Greenish coarse hard sandstone	5
Chocolate shale	10
Purple-gray fine-grained hard sandstone	4
Green-gray fossiliferous limestone	10
Fault	

Darton (1928, p. 113) placed these beds in the overlying Permian Abo formation on the basis of determination of fossils by G. H. Girty. However, fossils collected from these beds by the writer are the same as those from the underlying thick limestone beds and have been identified by Professor P. E. Raymond as typical Pennsylvanian forms. Furthermore, a sharper stratigraphic break exists at the top than at the base of this alternation of shale and limestone. Therefore these beds are considered to be part of the Magdalena rather than of the Abo.

The Magdalena limestone furnishes platy pebbles of limestone and some fragments of chert to eroding streams. Limestone pebbles in the Santa Fe formation are conspicuous only in the uppermost beds in the region west of the Gabaldon Badlands. This relation suggests that the Magdalena formation was not exposed in the Lucero anticline until late Santa Fe time. Chert pebbles are fairly common in nearly all horizons of the Santa Fe. Most of them are presumably secondarily derived from the Mesozoic conglomerates.

PERMIAN SERIES

Abo Formation.—On the gentle western limb of the Lucero anticline the red beds of the Abo formation underlie the broad lowland (Los Valles) between the hogbacks of Magdalena limestone and the high scarps of the Chupadera formation. The best continuous exposures, however, are found on Arroyo Carrizo, where the estimated thickness of interbedded red and red-brown sandstone and shale is 650 feet. Conglomeratic layers reported from the Abo elsewhere in New Mexico (Bryan, 1938, p. 202) were not found in the Lower Rio Puerco area.

The Abo formation was exposed in the Lucero anticline in late Santa Fe time and contributed pebbles of red sandstone to the uppermost gravel beds of the Santa Fe deposited west of the Gabaldon Badlands. Throughout the rest of Santa Fe time the

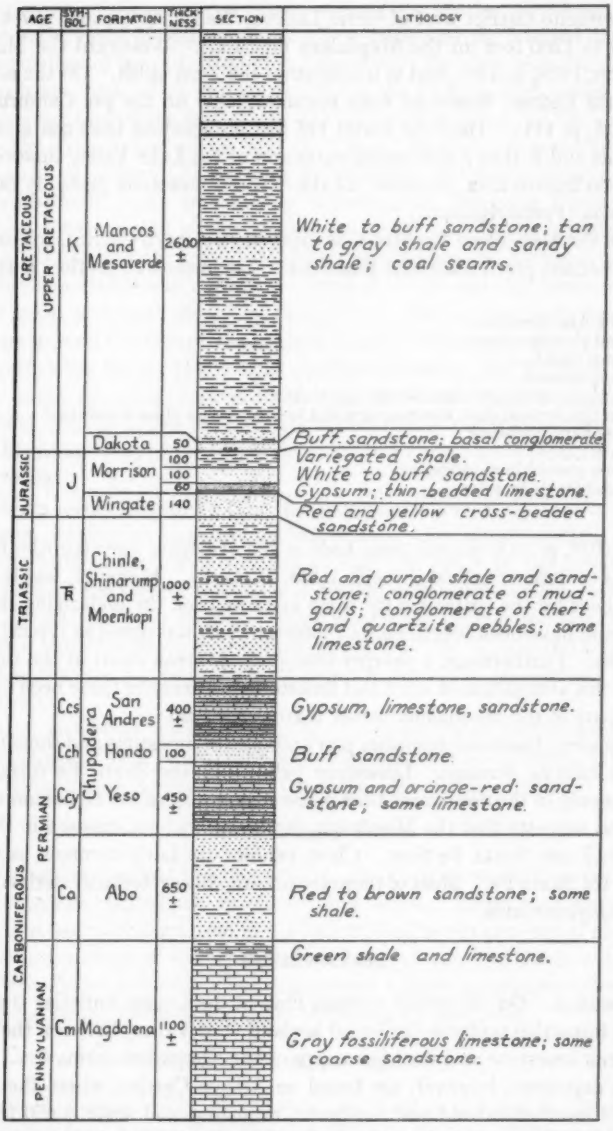

FIGURE 6.—*Stratigraphic column of pre-Tertiary rocks in Lower Rio Puerco area*

sandstone, shale, and conglomerate of the Abo formation of the Zuñi and Nacimiento uplifts may have been a source of red color for some of the beds of the Santa Fe formation, but clearly identifiable fragments are not present.

Chupadera formation.—In the Lower Rio Puerco area the Chupadera formation is

best exposed on the high east-facing scarps in the southwest part of the area (Pl. 1, fig. 1). It also forms the principal hogbacks east of Lucero Mesa, where resistant beds are repeated by faulting (Pl. 1, fig. 2). The Chupadera formation may be conveniently subdivided into three members—the Yeso member at the bottom, the Hondo sandstone, and the San Andres limestone.

The Yeso member consists of about 450 feet of interbedded gypsum and orange-red poorly cemented sandstone. A few layers of limestone are present. The gypsum beds in the Yeso east of Lucero Mesa total about 175 feet. The average thickness of individual gypsum layers is 5 to 15 feet; the maximum is 50 feet. The sandstone beds average 10 to 20 feet in thickness. The whole section is cut into a badland topography by steep streams which have worked headward from the east into the broad valley between Lucero Mesa and the hogbacks of the Lucero fault zone.

Where involved in the Lucero fault zone the soft gypsum and sandstone beds of the Yeso member exhibit intricate fold patterns, and portions of gypsum beds have flowed into the sandstone layers. The Yeso member is the locus of the numerous dikes, sills, and stocks on the Lucero anticline.

The Hondo member of the Chupadera formation consists of yellow massive sandstone beds, some of which are crossbedded. A few layers of gypsum are present. The total thickness is about 100 feet. The Hondo sandstone forms many of the hogbacks east of Lucero Mesa, and most of the roof pendant in the Major stock.

The upper or San Andres member of the Chupadera formation consists of about 400 feet of interbedded gray limestone and gypsum and white sandstone. The limestone beds are particularly resistant and hold up cliffs and hogbacks.

This tripartite subdivision of the Chupadera formation is correlated with the sections in the Socorro area east of the Rio Grande valley, in areas east of the Sandia-Manzano Mountains, and in the Pecos Valley (Lang, 1937). The thicknesses of the members and details of the sections vary, but the tripartite subdivision appears to be sound. The Hondo member is the equivalent of the Glorieta sandstone described by King (1942) in a paper published subsequent to the preparation of this report.

The Chupadera formation supplied limestone and sandstone pebbles to the uppermost gravels of the Santa Fe formation west of the Gabaldon Badlands. In early and middle Santa Fe time the Chupadera was exposed in the Zuñi and Nacimiento uplifts and presumably was a source of sand and calcium carbonate.

TRIASSIC SYSTEM

Triassic rocks underlie the lava-capped mesas and the alluvium of the broad valley of the Arroyo Colorado, in the western portion of the Lower Rio Puerco area (Pl. 4, fig. 2). Triassic rocks are also intimately involved in the Lucero fault zone. The thickness of the formation is difficult to measure because of faulting and landsliding and the consequent poor exposures. Under the basalt of Gallina Mesa is 600 to 800 feet of Triassic beds. Wells (1919, p. 19) reports a total thickness of 1150 to 1250 feet in the southwest corner of the area, and Darton (1928, p. 115) a minimum of 900 feet near the Rio San José. The figure 1000 feet is taken as the minimum thickness of the Triassic for the whole Lower Rio Puerco area. In the Zuñi Mountains the maximum thickness of the Triassic is about 1800 feet (Darton, 1928, p. 143).

The Triassic beds consist mostly of red and purple shale and sandstone. Less con-

spicuous are green and chocolate shale, greenish and yellowish sandstone, blue limestone, chert, and mud-gall conglomerate. Layers of pebbly conglomerate have well-rounded pebbles of quartzite, chert, jasper, quartz, and locally petrified wood.

The dominance of shale in the section causes landsliding, especially on edges of mesas capped by basalt or travertine. On the northern portion of Lucero Mesa the basalt cap is underlain by Triassic shale, and the scarp is covered with landslide masses (Pl. 5; Pl. 6, fig. 1). On the rest of the mesa, however, the basalt cap is underlain by the interbedded limestone, sandstone, and gypsum of the Chupadera formation, and the scarp is free from landsliding (Pl. 1, fig. 1).

Possibly only the uppermost or Chinle formation of the western New Mexico Triassic system is represented in the Lower Rio Puerco area, but the pebble beds, purple shales, and mud-gall conglomerates characteristic of the Shinarump conglomerate and the Moenkopi formation to the west suggest that the middle and lower Triassic also may be represented.

The Triassic formations were the most important contributors of the abundant pebbles of quartzite, chert, quartz, and petrified wood in the Santa Fe formation. Such well-rounded pebbles were broken and rerounded during the transportation in Santa Fe time. The Triassic rocks also furnished most of the red sand and clay which gives much of the Santa Fe formation its red and pink color.

JURASSIC SYSTEM

Wingate formation.—Exposures in the Lower Rio Puerco area are best on the scarp of Mesa Gigante, north of the Rio San José, where 110 feet of massive beds of pink crossbedded sandstone is overlain by 30 feet of pure white sandstone with some layers of yellow, purple, red, and green sandstone. The Wingate is also exposed on the bluffs west of the Arroyo Colorado valley in the Laguna Reservation, where pink and white cross-bedded sandstone is intruded by sills.

The Wingate formation contributed sand to the Santa Fe streams.

Morrison formation.—This formation, in the Lower Rio Puerco area, includes (1) the Todilto member at the base, (2) a sandstone member formerly called Navajo (Darton, 1928, p. 119) but not the equivalent of the Navajo of Arizona and Utah, and (3) the shale member characteristic of the Morrison almost everywhere (Baker, Dane, and Reeside, 1936). It is exposed on the slopes of Mesa Gigante and Mesa Rosario, on the high bluffs west of the Rio Colorado valley, and at the northern end of the Lucero fault zone. There is no apparent unconformity between the Morrison and the underlying Wingate formation.

The Todilto member has at the base a distinctive 3- to 15-foot layer of thin-bedded platy limestone characterized locally by small folds of contemporaneous deformation. This limestone is overlain by a massive bed of gypsum 40 to 60 feet thick. The middle member consists of about 100 feet of white to red sandstone. The upper member consists of 100 feet of white, buff, green, and red shale. No pebble beds were noted.

The Morrison formation contributed sand and presumably some red coloring matter to the Santa Fe streams.

UPPER CRETACEOUS SERIES

Dakota sandstone.—In the Lower Rio Puerco area the Dakota sandstone is well exposed on Mesa Rosario and in the area of faulted Cretaceous rocks north of the Rio San José. It consists of about 50 feet of buff and white thickly bedded calcareous sandstone with a 5-foot layer of gray carbonaceous shale in the middle. Locally the base of the formation is marked by a fine quartz conglomerate or coarse grit. This conglomerate is the only evidence for the long interval of erosion during the Lower Cretaceous, because the Dakota rests on the older rocks with apparent conformity.

The Dakota sandstone furnished sand and a few quartz pebbles to the Santa Fe streams.

Mancos shale and Mesaverde formation.—The area north of the Rio San José and east of Mesa Gigante is underlain largely by the Mancos and Mesaverde formations. The stratigraphy and structure of this section have been studied by Hunt (1936, 1938; Sears, Hunt, and Hendricks, 1941). In this area the thickness of these two formations is about 2600 feet. To the north and northwest they are overlain by the Lewis, Pictured Cliffs, Fruitland, Kirtland, McDermott, and Ojo Alamo formations, all of uppermost Cretaceous age; and the Puerco, Torrejon, and Wasatch formations, of Eocene age. The total thickness of post-Dakota formations here is about 5500 feet (Dane, 1936, p. 91). However, the McDermott and younger formations were derived in part from highlands to the north and northeast (Reeside, 1924, p. 51) and may never have extended as far south as the Lower Rio Puerco area. In regions south of the Lower Rio Puerco area the Upper Cretaceous rocks have a maximum thickness of 4000 feet (Winchester, 1920, p. 6; Wells, 1919, p. 20). The maximum original thickness of Upper Cretaceous rocks in the Lower Rio Puerco area, then, is probably in the neighborhood of 4500 feet.

The Mancos shale and Mesaverde formation represent the off-shore and near-shore facies respectively of the Upper Cretaceous sea, which advanced from the northwest (Sears, Hunt, and Hendricks, 1941). In the Lower Rio Puerco area the Mancos shale consists mostly of gray and tan soft shale with three thick sandstone beds near the base. Sandstone members of the Mesaverde formation interfinger with the upper part of the Mancos shale; they are white to buff sandstone commonly stained with limonite and bearing limonite concretions. Layers of shale and coal are present in some of the members. Two coal mines are now in operation within the Lower Rio Puerco area, the Ferro Mine and the Cañoncito Mine. Many others have been abandoned.

The Upper Cretaceous rocks furnished most of the light-colored sand and silt which makes up a large part of the Santa Fe formation in the Lower Rio Puerco area. They also furnished limonitic concretions and fragments of petrified wood.

The uppermost Cretaceous McDermott, Ojo Alamo, and Animas formations and the Eocene Wasatch formation of the San Juan basin in northwestern New Mexico contain pebbles of chert, quartzite, quartz, and andesite (Reeside, 1924; Dane, 1936). These pebble beds probably owe their origin to the preliminary uplifts and vulcanism in the San Juan and Jemez Mountains to the north and east (Reeside, 1924, p. 51).

These formations apparently thin to the south (Dane, 1936) and probably never covered an area much larger than the present area of outcrop. Consequently they probably did not contribute many pebbles to the Santa Fe streams.

MIDDLE TERTIARY VOLCANICS

Extensive nonbasaltic volcanic activity characterized the middle Tertiary in much of western New Mexico (Bryan, 1938, p. 204). The great centers of the Datil-Mogollon Mountains, the Sierra de los Valles, and Mount Taylor covered thousands of square miles with lava and tuff. This plate of volcanics was deformed in pre-Santa Fe time and contributed pebbles to the Santa Fe in many areas (Figs. 4 and 5).

Tuffaceous alluvial deposits representing very late phases of this period of vulcanism have been preserved under the Santa Fe formation at a number of localities. Denny (1940a) describes 5000 feet of tuffaceous playa and alluvial deposits of the Popotosa formation in the San Acacia area at the southern end of the Albuquerque-Belen basin. These beds rest unconformably on the main mass of mid-Tertiary volcanics and are overlain unconformably by the Santa Fe. Northeast of the Sierra de los Valles center Smith (1938) has found and described the Abiquiu formation, which consists of at least 1200 feet of tuffaceous deposits. Cabot (1938) describes 1200 feet of Picuris tuff 25 miles east of the Abiquiu area. The Abiquiu and part of the Picuris are closely related in age to the Santa Fe formation, which rests on them conformably in places and unconformably in other places. Bryan and McCann (1937, p. 817) mapped a small upfaulted remnant of pre-Santa Fe andesitic tuffaceous sandstone, 250 feet thick, in Benevides Hill at the northern edge of the Lower Rio Puerco area.

In the Rio Puerco valley just south of U. S. Highway 66 is Cerro Colorado (Wright, 1943), which consists of trachytic lavas and pyroclastics interbedded with sandstone of external origin and intruded by a quartz latite plug. Cerro Colorado is probably Miocene, *i.e.* either pre-Santa Fe or early Santa Fe, an outlying volcano of the Mount Taylor center.

Bryan states (personal communication) that Cerro Tomé, 5 miles south of Los Lunas on the Rio Grande, just east of the Lower Rio Puerco area, consists of andesitic and rhyolitic tuff and lava of probable pre-Santa Fe age.

SANTA FE FORMATION

INTRODUCTION

The Santa Fe formation is an accumulation of late Tertiary deformed unconsolidated basin deposits occupying the Rio Grande depression and adjacent areas. It carries at best a loose definition. Bryan (1938, p. 205) lists the following criteria:

> "(1) All the beds are slightly cemented, and the finer-grained members have concretions of calcium carbonate; (2) all the deposits are deformed, mostly by normal faults, although in the centers of the basins the deformation is so slight as to pass unnoticed except under intensive search; (3) the beds within any one basin are of diverse lithologic types, ranging from coarse fanglomerate to fine silt and clay, and abrupt changes in kind and size of the contained pebbles are characteristic; (4) these markedly different materials attributed to one formation conform in their arrangement to a geographic pattern consistent with the laws of deposition in basins."

The name Santa Fe marl was introduced by Hayden (1869, p. 167-170) to deformed unconsolidated deposits near Santa Fe, New Mexico. They were considered to be of lacustrine origin largely because of the widespread calcareous layer on top of the unconsolidated sand and gravel. But they are now recognized as alluvial beds (Johnson, 1903; Bryan, 1938) and the so-called marl as a capping of caliche formed as a soil zone in post-Santa Fe time (Bryan and McCann, 1937). Other mappable units have been separated from the mass of material originally included under the term Santa Fe. Such are certain Quaternary basalt flows and rhyolite tuffs, dune sand, and valley fill, and certain middle Tertiary (?) tuffaceous alluvial deposits (Bryan, 1938, p. 217–219).

TOPOGRAPHY AND EXPOSURES

The sands and gravels of the Santa Fe formation are but slightly cemented, so have been easily eroded by the Rio Grande and its tributaries. The Rio Grande depression is, then, a topographic as well as a structural depression. The best exposures of the Santa Fe are on the scarps of mesas and buttes capped by basalt, caliche, or cemented gravels. The Ceja del Rio Puerco, the remarkably straight scarp at the western edge of the Llano de Albuquerque, for instance, affords almost continuous exposures for a distance of 70 miles (Pl. 3, fig. 2).

One other area of excellent exposures is the Gabaldon Badlands (Pl. 4, fig. 1), where Santa Fe playa and fan deposits have been dissected almost completely over an area of about 7 square miles. Due to the gypsiferous character of some of the playa beds, vegetation is scarce and minute details of the bedding are well revealed.

The extensive plain south of the Gabladon Badlands is picturesquely termed by the local inhabitants Sabinas Solas, or "Lonely Cedars." It covers an area of about 175 square miles and is practically devoid of exposures of Santa Fe, although presumably underlain thereby.

FORMATION OF BASIN DEPOSITS

The Santa Fe formation was deposited in a subsiding structural depression composed of a number of basins separated end to end by structural constrictions. Each basin was tectonically independent and had a characteristic geographic pattern.

Bryan's (1938, p. 221–225) classification of the basins of the Rio Grande depression essentially involves the presence of none, one, or more of the following five features: (1) surface inflow from outside the basin, (2) ground-water inflow from outside the basin, (3) surface outflow, (4) ground-water outflow, and (5) a lake or high water table in the center of the basin through which the water can be consumed by intense evaporation, transpiration, or chemical combination.

Conceivably, then, there could be 32 types of basin. For the purposes of the present discussion, however, only two general types are considered: (1) basins which have surface outflow and (2) basins which do not have surface outflow.

Other factors being equal, basins drained by a surface stream of major size will have two principal types of deposit: (a) alluvial-fan deposits consisting of gravel near the mountains and grading into sand, silt, and even clay toward the axis of the basin, and

(b) river gravel distributed along the axis of the basin, with some fine sand, silt, and clay. If the river originated outside the basin, the river gravel may include resistant well-rounded pebbles derived from a distant source. Basins with no surface outflow will also have two principal types of deposit: (a) a peripheral band of alluvial-fan material, and (b) a central area of playa or lake deposits consisting of fine sand, silt, and clay with gypsum and other chemical precipitates and evaporites.

The geography of the basin is controlled primarily by three interacting factors:

(1) Local and regional tectonic changes. Tectonic forces determine the original shape, area, and depth of the basin; the volume and distribution of rocks of different lithologies in the surrounding highlands; and the major drainage features of the basin. Vulcanism within the basin may locally alter the drainage pattern. The amount and rate of subsidence of the basin and uplift of the surrounding highlands determine in part the gradients of the streams and thus the rate of erosion and deposition and the lithology of the deposit. If the rate of relative movement is constant, the type of deposition at any one place remains constant, other factors being equal. If the basin is drained by a through-flowing river, a change in base-level outside the basin (produced perhaps by tectonic forces) may immediately or ultimately affect the base level within the basin, thereby changing the rate of erosion or deposition in the center of the basin.

(2) Lithology of the surrounding highlands. If the highland rock is resistant, the streams are steep and can carry gravel and coarse sand far into the basin; if it is not resistant, then streams of low gradient can carry the abundant supply of fine-grained weathered material. Furthermore, if the highlands are mostly sandstone, for instance, they will furnish little but sand to the streams. Travel of detritus from its source to the alluvial fans ordinarily is too short to reduce much of the sand to clay sizes. If the highlands are mostly shale, the sediment deposited in the basin will be mostly clay and silt. In a basin drained by an axial river, however, the clay, silt, and even much of the sand may be carried out of the basin.

(3) Climate. This factor controls weathering and thus the size and quantity of detritus supplied to the streams. It also determines the volume and rate of stream discharge and thus the competence of the streams. In a climate characterized by cloudbursts and occasionally large stream discharge, coarse sediment may be moved on relatively gentle gradients. In a basin with no surface outflow the total rainfall, distribution of rainfall, and evaporation are climatic elements which determine (along with the dimensions of the basin and the permeability of the rocks) whether or not the basin will be occupied by a fresh water lake, a playa lake, or a dry playa. A basin with a through-flowing axial stream reflects the climate only in the alluvial-fan deposits; the character of the axial river deposits depends on the regime of the through-flowing river, which derives its major water supply from areas outside the basin.

GEOGRAPHY OF THE ALBUQUERQUE-BELEN BASIN

In the Albuquerque-Belen basin the Santa Fe formation contains alluvial-fan deposits, axial river deposits, and playa deposits. The distribution of these deposits is shown on two paleogeographic maps of west-central New Mexico, one for early and

middle Santa Fe time (Fig. 4), the other for late Santa Fe time (Fig. 5). The maps also show the major structural elements of the highlands bordering the basin, the distribution of the pre-Santa Fe rocks which furnished distinctive types of sediment to the Santa Fe streams, and the drainage pattern of the whole area as revealed by the vertical and horizontal changes in lithology in the Santa Fe formation.

Information for the eastern portion of the basin is taken from Bryan (1938, p. 206), and for the southern end from Denny (1940a, p. 97). The drainage direction west of the Zuñi Mountains is based on the work of McCann (1938).

AXIAL RIVER GRAVEL

As traced by Bryan (1938, p. 206), the train of axial river gravels runs down the eastern portion of the asymmetric Albuquerque-Belen basin, approximately along the course of the modern Rio Grande (Fig. 5). Near the southern end of the basin, the ancient river turned eastward and passed across the present area of the Los Pinos Mountains, returning to the main axis of the depression south of Socorro. The western portion of the depression in this region of diversion was occupied by the Socorro playa, which was separated from the through-flowing basin by an alluvial divide and the La Joyita Hills (Denny, 1940a, p. 97).

Denny (1940a, p. 89) states that the river deposits consist of gravel, sand, silt, and red and green clay. The pebbles are large (average size 3 inches, maximum 7 inches), well-rounded, and resistant. River gravel and sand are cleaner and better sorted than alluvial-fan gravel and sand. River pebbles are larger than the alluvial-fan pebbles which sometimes reach the central portion of the basin. If the river originates outside the basin, the river gravel includes types derived from distant areas. It cannot be determined what parts of Santa Fe time are represented by the river gravel. Bryan reports (personal communication) that several hundred feet of river gravels are exposed in the Santo Domingo Valley, north of the Albuquerque-Belen basin, and that the Santa Fe in this region is at least 1500 feet thick. This thickness may represent the whole of Santa Fe time or only the upper part.

ALLUVIAL-FAN DEPOSITS

General statement.—Alluvial-fan deposits consist of poorly sorted angular and subangular gravels and sands, locally including layers of silt, clay, or even limestone. Cross-bedding, channeling, minor unconformities, and sharp stratification are caused by the irregular lateral migration of streams over the area of deposition between the pediment or mountain front and the axial river floodplain or playa. The general factors governing the lithology of alluvial-fan deposits were reviewed in the section on formation of basin deposits.

The western alluvial-fan deposits of the northern part of the Albuquerque-Belen basin were subdivided into three members by Bryan and McCann (1937) in the Northern Ceja area, immediately north of the Lower Rio Puerco area (Fig. 2). These members, the Lower Gray, Middle Red, and Upper Buff, were traced southward by the author along the western portion of the Albuquerque-Belen basin to the San Acacia area, where no subdivision had been possible (Denny, 1940a). It is planned in future work to carry these same subdivisions eastward down the Rio Jemez to the

axis of the basin. In this way the river gravel may be dated with respect to the fan deposits and especially to the playa deposits.

Lower Gray member.—The Lower Gray member consists generally of white to gray fine- to medium-grained clean sandstone cemented by calcium carbonate. In certain horizons the cement is so conspicuous that it forms large crystals of calcite around the sand grains. Such "sand crystals" are rounded by weathering and produce distinctive subspherical pebbles $\frac{1}{4}$–$\frac{3}{4}$ inch in diameter. The cleavage of the calcite is exhibited on the broken surfaces of the sand crystals.

The Lower Gray member of the Santa Fe formation may be found immediately west of the Apache graben, a block of the Santa Fe formation faulted down into Cretaceous rocks on the western edge of the Albuquerque-Belen basin. This and all other post-Cretaceous material of the region were mapped by Hunt (1936; 1938) as undeformed "soil cover and Santa Fe formation."

The best exposures of the Lower Gray member are in secs. 1 and 12, T.10 N., R.2 W., where at least 250 feet of medium- to coarse-grained white sandstone and buff sand rests unconformably on Cretaceous rocks and is faulted against the Middle Red member. Differential weathering of the abundant calcareous cement of the resistant layers obscures the finer details of the bedding. Pebbles of quartzite, chert, quartz, and granite are scattered throughout the sandstone.

At a number of other localities along the block bordering the Apache graben on the west (sec. 31, T. 11 N., R.1 W.; secs. 25, 35, and 36, T.10 N., R.2 W.; and sec. 9, T.9 N., R.2 W.) patches of white calcareous sandstone and gravel, 10–60 feet thick, rest unconformably on Cretaceous rocks. These beds are tilted 2°–9° and are faulted against Cretaceous rocks; they therefore must be the basal beds of the Santa Fe formation rather than cemented Quaternary alluvial cover, which is undeformed and conforms to stream grades somewhat above the present streams. Furthermore, this basal Santa Fe gravel contains mostly quartzite, chert, quartz, granite, and in some cases conspicuous nonbasaltic volcanics. These pebbles must have been derived from the Zuñi uplift and Mount Taylor to the west. Although the Quaternary gravel contains these same types, presumably secondarily derived from the Santa Fe formation, it also contains a large proportion of angular pebbles of ironstone, sandstone, and petrified wood, types which were obviously derived from near-by hills of Cretaceous sandstones. Remnants of this cemented Quaternary gravel overlie tilted beds of the Santa Fe formation in the southern part of the Apache graben.

The distinctive white calcareous sandstone and gravel of the Lower Gray member cannot be found south of U. S. Highway 66. It may be buried in this region by later beds or it may grade laterally southward into darker beds indistinguishable from the middle member of the Santa Fe. Such gradation might easily arise from the geographic pattern of the basin and adjacent highlands. Presumably in early Santa Fe time the streams that deposited the fan material in the Apache graben region arose mostly in the areas of Cretaceous sandstone and shale immediately to the west. South of the Apache graben region, streams arising in the west would derive more material from the darker pre-Cretaceous rocks of the Zuñi and Lucero uplifts, and from the darker volcanic rocks of the Mount Taylor area. The lower Santa Fe of this region may consequently be darker and not readily recognizable as the equivalent of the Lower Gray member. Unfortunately, continuous outcrop does not exist.

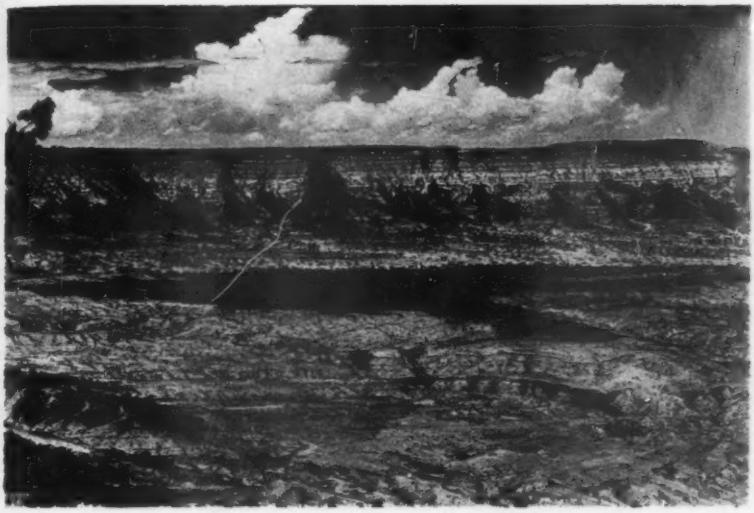

FIGURE 1. EASTERN SCARP OF LUCERO MESA

Basalt cap underlain by limestone, gypsum, and sandstone of Chupadera formation. No landslide blocks, but only talus cones. (*Cf.* Pl. 5.) Basalt on right rests on travertine which was deposited in a channel in the Chupadera. Dissected erosion surface at base of mesa is cut on Yeso sand and gypsum.

FIGURE 2. LUCERO FAULT ZONE

Directly north of Arroyo Carrizo. Abo and Magdalena formations on west (left) dip sharply to the east and are separated form the Yeso member of the Chupadera by a fault (saddle left of hogback). Hogback made of Hondo sandstone and San Andres limestone capped by travertine. The gently eastward dipping Triassic shale and sandstone of the right foreground are overturned to the west a few hundred feet to the north and are separated from the Chupadera by a second fault. The two faults join in the middle foreground, completely eliminating the Chupadera, and placing the Abo on the west against the Triassic on the east.

LUCERO MESA AND LUCERO FAULT ZONE

FIGURE 2. SAND DIKE
Small fault in Santa Fe formation at north end of Lower Rio Puerco area. Gully has cut along edge of cemented zone.

FIGURE 1. CARRIZO FAULT
Half a mile north of Arroyo Carrizo. Reddish sand and silt of Middle Red member of Santa Fe formation faulted down on right (east) against red Triassic shale. Note man on fault plane on horizon.

CARRIZO FAULT AND SMALL SAND DIKE

The pebble content of the Lower Santa Fe in the Apache graben region also permits speculation on the changing geographic conditions of Santa Fe time. Some of the pebbles may have come from the conglomeratic layers of the McDermott, Ojo Alamo, and Wasatch formations in the San Juan Basin to the northwest. Others may have come from the Nacimiento region, suggesting perhaps that the whole northern portion of the basin drained southward into Gabaldon playa in early Santa Fe time. This suggestion is not supported by the generally finer texture of the Lower Gray member in the Northern Ceja area to the north, *i.e.* upstream from the Apache graben area, but exact time equivalence for the sections exposed in these two areas is not proved. Most of the quartzite-chert-granite types probably came from the Zuñi uplift and the volcanic types of pebbles from Mount Taylor. Mingling of pebbles from these two major source areas suggests considerable lateral shifting of streams during Santa Fe time, for the streams from the Zuñi area had to flow around the southern edge (or perhaps even around the northern edge) of the Mount Taylor field to reach the Apache graben area (Fig. 4). The impossibility of tracing closely the thin and discontinuous pebbly horizons makes difficult the reconstruction of the details of the geographic pattern.

Middle Red member.—The Middle Red member differs from the Lower Gray mostly in color, and this distinction disappears toward the south. The unweathered sandstone is white or pink, but wash from interbedded red silt and clay colors cliffs red. Calcareous cement and sand crystals are not so conspicuous as in the Lower Gray member.

Bryan and McCann (1937, p. 817) remark that the difference in color between the Lower Gray and the Middle Red members in the Northern Ceja area reflect either (1) a drainage change resulting in an increasing contribution of sediment from the Sierra Nacimiento where Triassic and Permian red beds were exposed, or (2) a stripping of the light-colored Cretaceous rocks from this uplift, thereby exposing the red beds.

The best exposures are in the Apache graben at T.10 N., R.1 W., where at least 1000 feet of eastward-dipping reddish alluvial beds is exposed. The base is faulted against the Lower Gray member, and the top is poorly defined. The Middle Red at this locality consists of pink and buff calcareous sandstone stained reddish by wash from interbedded clay and silt layers. Gravel lenses are more common than in the Lower Gray member. Some of the gravel layers contain pebbles of quartzite, chert, quartz, and granite, presumably derived from the Zuñi uplift and in part from the Nacimiento uplift. Other layers consist almost entirely of pebbles of coarse latite and gray to brown fine-grained rhyolite or quartz latite, derived from the Mount Taylor region. The alternation of gravel layers derived from two different sources illustrates the mechanism of deposition on coalescing alluvial fans. Storms concentrated in the Zuñi area caused transportation of detritus from that area to the basin of deposition. Then storms concentrated in the Mount Taylor region caused streams from that area to bring volcanic pebbles to the same point in the basin of deposition.

The discontinuous exposures of the Santa Fe formation along the Carrizo fault east of Lucero Mesa are mostly pink and buff sand and tan and red silt with layers of gravel in which volcanic pebbles are the most conspicuous constituents. At one locality, in sec. 19, T.6 N., R.2 W., red sand and silt are underlain by at least 30 feet of

distinctive bright-yellow sand which contains scattered wind-polished pebbles of quartzite, quartz, chert, and rhyolite. Southward the alluvial beds of the middle member interfinger with the playa deposits of the Gabaldon Badlands. The total measured thickness of the interfingering alluvial beds of both the lower and middle members, which here are indistinguishable, is 4100 feet. The base is not exposed. These beds are overlain here by the fan deposits of the Upper Buff member. The complete section of the Santa Fe here is described below in the discussion of the playa deposits.

Upper Buff member.—The Upper Buff member consists of buff, pink, white, and tan sand with numerous layers of gray gravel toward the top. It may be traced almost continuously for 70 miles along the Ceja del Rio Puerco where it has a maximum exposed thickness of 250 feet (Fig. 7; Pl. 3, fig. 2). At the northern end of the Ceja the pebbles have an average size of 2 inches and a maximum of 4 to 6 inches; they consist of quartzite, chert, quartz, and granite from the Sierra Nacimiento and andesite and other nonbasaltic volcanic types presumably from the adjacent Sierra de los Valles. The increase in stream gradients indicated by the coarsening of texture of the Upper Buff member was probably the result of renewed uplift of this general area to the north (Jemez Mountains).

Southward along the Ceja the only significant changes in the lithology of this member are the gradual reduction in average grain size and the gradual disappearance of volcanic pebbles from the gravel layers. Here most of the depositing streams appear to have come from the west rather than the north, and obtained pebbles from the pre-Cretaceous rocks exposed in the Zuñi and Lucero uplifts.

Along the Ceja the uppermost beds consist of gray gravel and buff sand with conspicuous stream cross-bedding and channeling; this series ranges in thickness from 0 to 80 feet. The top 10 feet is cemented into massive caliche by the action of ground water during the formation of the Ortiz pediment, and nodules of caliche are present in the sand and gravels below the massive cap. Possibly some of the gravel at the top of this series was deposited as pediment gravel by the streams which cut the Ortiz surface, and some of the sand may be wind-blown sand deposited in Ortiz time. However, the bulk of the sand and gravel is probably of Santa Fe age, and the thickness varies due to channeling, nondeposition, and pre-Ortiz deformation. In the Apache graben the sands and gravels similar to these are tilted as much as 30°. Gravels are present in the lower horizons of the Upper Buff member, although they are not so conspicuous as at the top. Probably the change from dominant sand to conspicuous gravel in the Upper Buff member and thus in the uppermost part of the Santa Fe formation reflects an increase in stream gradients brought about by the rise of the bordering highlands. This movement was the beginning of the deformation which reached a climax shortly after the cessation of deposition.

In the Sand Hill fault zone at the northern edge of the Lower Rio Puerco area the upper beds of the Upper Buff member rest unconformably in places on the main mass of the member (Pl. 3, fig. 1). Bryan and McCann (1937, p. 815), who originally mapped this fault zone, considered that the unconformable gravel and sand are "the Quaternary cover of the Llano de Albuquerque." It is more likely, however, that the entire section here is part of the Upper Buff member of the Santa Fe, and that the

FIGURE 1. WEST SAND HILL FAULT
Upper Buff member of Santa Fe formation on right (east) faulted down against Middle Red member on left. Unconformity within Upper Buff. Note pronounced drag on beds below unconformity, and slight drag on beds above. Sand dike along fault plane. For sequence of events, *see* Figure 10.

FIGURE 2. EAST SAND HILL FAULT
Ceja del Rio Puerco. Caliche on the east (left) side of the fault is 150 feet thick, on the west side only 10 feet. Note truncation of beds of the Upper Buff member of the Santa Fe west of the fault by the caliche of the Ortiz surface. Cliff dunes of Ceja above the scarp. Albuquerque volcanoes and Manzano Mountains in the left distance. (For detail of fault, *see* Pl. 3, fig. 3.)

FIGURE 3. EAST SAND HILL FAULT
Calichified layers on left (east) faulted down against tan sand and silt of Upper Buff member of Santa Fe formation. Top 10 feet of caliche overlies the fault.

SAND HILL FAULT ZONE

FIGURE 1. GABALDON BADLANDS
Tan playa deposits of Santa Fe formation on west limb of Gabaldon Badlands.

FIGURE 2. VIEW NORTHWEST FROM CERRO VERDE
Cinder Butte in left foreground, Carlos Mesa in right foreground, Arroyo Colorado in middle-distance, Mount Taylor on left skyline.

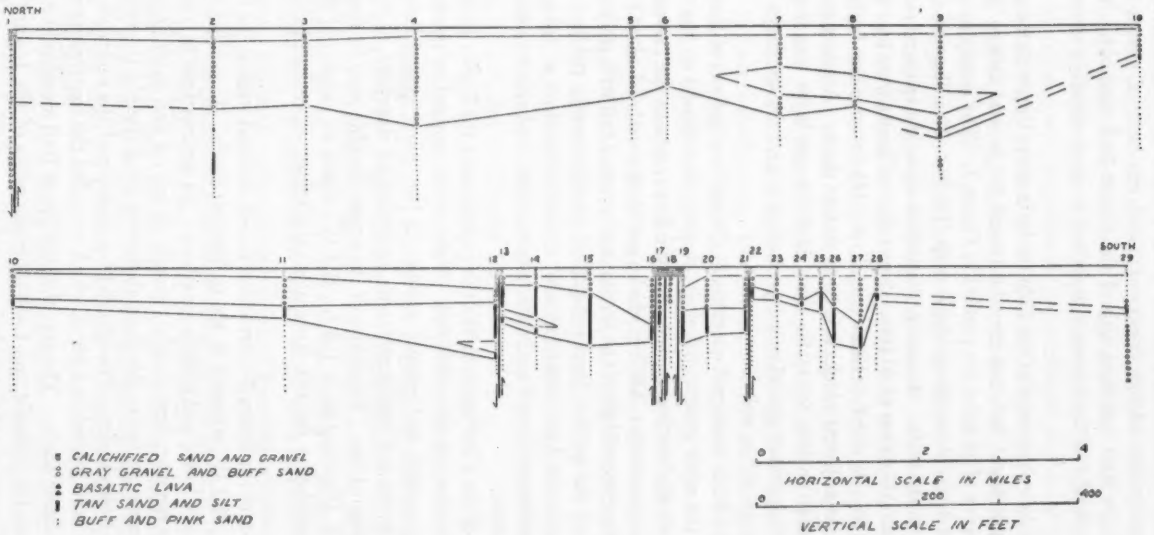

FIGURE 7.—*Stratigraphic sections along the Ceja del Rio Puerco*
For location of sections, *see* geologic map (Pl. 8).

unconformity represents local deformation in late Santa Fe time. When traced southward the angular discordance disappears, and the beds of gravel and sand thicken and interfinger with the main unit of the Upper Buff member. The structural history of the Sand Hill fault zone is described in more detail in the section on geomorphology.

In the 70 miles of the escarpment of the Ceja the beds of the Upper Buff member are essentially flat. Individual horizons may be traced for several miles. Measured sections over a distance of 28 miles are plotted in Figure 7. The localities of the sections are numbered 1 to 29 on the geologic map (Pl. 8). The diagram shows the lenticular character of the beds. A notably distinctive layer is a tan sand and silt bed which has a maximum thickness of 60 feet. Several small faults were found with the aid of this key horizon. In one thin block (Fig. 7, sec. 18) between two faults this tan layer is lacking; in the adjacent blocks it is 20 to 40 feet thick. Apparently the central block was uplifted in late Santa Fe time, and the tan layer was removed by erosion. Then the uppermost gravel was deposited, and later movement on the same faults displaced the gravel as well.

The beds of Santa Fe in scattered outcrops in the shallow valleys of the Llano de Albuquerque have the same general lithology as the beds exposed on the Ceja, but are finer-grained. At the northwest base of Cerro Los Lunas at the eastern edge of the Llano is a section more than 300 feet thick consisting mostly of tilted buff, pink, and white sand. Near the middle of the section are layers of tuff with pellets of pumice. Near the top of the section layers of gravel contain mostly pebbles of basalt derived from the adjacent Los Lunas volcano, which is therefore of Santa Fe age. This gravel also contains pebbles of quartzite, quartz, chert, and granite brought from the west and northwest.

On the west side of the Rio Puerco valley the exposures of the Upper Buff member of the Santa Fe formation are discontinuous. They are recognized by the dominance of quartzite, chert, quartz, and granite pebbles in the many gravel layers. The gravel lenses of the lower and middle members, as explained elsewhere, have volcanic pebbles as the dominant type. Exposures of the upper member may be found in the road cuts along U. S. Highway 66 in T.9 N., R.2 W., where an estimated 200 to 300 feet of the upper member is faulted down against Cretaceous rocks in the Apache graben.

The upper member of the Santa Fe formation is well exposed west of the Gabaldon Badlands in T.6 N., R.2 W., where it is 400 to 700 feet thick. It overlies the playa and fan deposits of the lower and middle members. As summarized in Table 1 and Figure 8, the upper member here consists mostly of gravel and sand deposited on alluvial-fans by streams graded to the through-flowing axial river in the eastern part of the Albuquerque-Belen basin. The alluvial-fan deposits of the underlying middle and lower members were graded to a playa which occupied the southwestern portion of the Albuquerque-Belen basin. The gravel in the Upper Buff member here contains pebbles derived from the Triassic and Carboniferous rocks of the Lucero anticline just to the west. The gravels of the underlying middle member contain pebbles from the Mount Taylor and Datil-Mogollon volcanic fields farther west and southwest. These lithologic changes reflect certain geographic changes produced by the renewed uplift of the Lucero anticline in late Santa Fe time.

The alluvial fan deposits of the lower and middle members had probably covered much of the truncated Lucero anticline. As the uplift of the anticline was renewed in late Santa Fe time these beds were stripped off and their volcanic pebbles were redeposited in the lower beds of the upper member. The underlying Triassic rocks were thereby exposed, and they thereafter contributed pebbles of quartzite and chert. The rounded quartzite pebbles of the Triassic conglomerate beds are found in the Upper Buff member freshly broken and rerounded. They form a distinctive rubble on the top of gravel beds.

The gravel layers in the Upper Buff member are thicker and coarser toward the top, where they include pebbles of limestone and sandstone from the Carboniferous rocks, pebbles of travertine from the spring deposits, and pebbles of monzonite from the Major stock. These changes in lithology reflect the continued rise of the domed rocks of the Lucero anticline as movement took place along the late- and post-Santa Fe Carrizo fault. The Triassic rocks were partly stripped off and the Carboniferous rocks and the monzonite stock were exposed. Springs then as now broke out on the pre-Santa Fe Lucero fault zone. The conspicuous calcareous cement in these upper beds is a result of erosion of the Carboniferous limestone and of the activity of the springs along the Lucero fault zone.

The massive cemented gravel at the top of the Santa Fe formation here is identical in pebble content to the near-by Quaternary pediment gravel, except for the absence of basalt pebbles. The Santa Fe beds are tilted locally as much as 30° and are faulted against the pre-Tertiary rocks on the Carrizo fault. They are conformable with the underlying fan and playa deposits. The Quaternary gravel, on the other hand, is undeformed and contains distinctive quantities of basalt pebbles derived from the post-Santa Fe lava flows of Lucero Mesa.

PLAYA DEPOSITS

General Statements.—The area known as the Gabaldon Badlands, mostly in T.6 N., R.2 W., is underlain by at least 4100 feet of playa deposits which here represent the lower and middle members of the Santa Fe formation (Pl. 4, fig. 1). The beds are tilted uniformly 10° to 15° W. They form the gently dipping western limb of the Gabaldon anticline, the axis of which trends N. 20° W. and runs through the western edge of Cerros Mohinos, where basaltic sills and flows are interbedded with the playa and fan deposits.

The area is practically bare of vegetation, except along the dry sandy washes, probably largely because the sediments are gypsiferous. The slopes formed on the finer-grained beds are soft and rounded, except where undercut by streams. Drainage of these slopes is by means of sinkholes and underground channels. The slopes formed on sandy beds are generally steeper. Cliffs are held up by beds of well-cemented sandstone.

Lithology.—The playa deposits have a maximum measured thickness of 4100 feet, and the base is not exposed. The basal tan portion 3600 feet thick extends over the whole area of the Gabaldon Badlands. The playa deposits consist dominantly of tan, buff, and brown sand and brown and red gypsiferous silt and clay (Table 1). The uppermost 400 feet of the thickest portion are distinctly more reddish. The layers are thinly and regularly bedded, but the stratification is partly masked by the desic-

TABLE 1.—*Lithology of playa deposits of the lower and middle members of the Santa Fe formation and the overlying alluvial fan deposits of the upper member*

Column 1 refers to section 1 in Fig. 8A; column 2 to section 2.

1	2
Gray massive gravel *Feet* 200 Gray massive lime-cemented coarse gravel with the following pebble types, in order of abundance: limestone, travertine, red sandstone, chert, quartzite, and monzonite, all locally derived. Maximum diameter of pebbles 30 inches; average diameter 1 inch. Some pink sand interbedded with the gravel.	*Light-colored sand and gravel* *Feet* 700 Buff and pink sand; gravel with pebbles of limestone, quartzite, and chert.
Gray gravel and light-colored sand 200 Gray lime-cemented gravel, with pebbles of quartzite (freshly broken), limestone, travertine, chert, sandstone, latite and rhyolite. Pink, white, and greenish sand; red and brown gypsiferous silt.	
Volcanic gravel and light-colored sand 100 Gray lime-cemented gravel with pebbles of rhyolite and latite, quartzite, chert, and limestone.	*Light-colored sand and volcanic gravel* 100 Pink, buff, white, and greenish sand; tan, brown and red silt. Some gravel layers with pebbles of rhyolite and latite, quartzite, chert, and limestone.
Pink sand and gravel 400 Pink sand with layers of gravel, locally lime-cemented. One conspicuous cliff-forming bed 100 feet above the base. Pebbles of rhyolite and latite, quartzite, limestone, sandstone, and chert. Some red and brown silt.	*Red playa deposits* 400 Red and brown gypsiferous silt; red, brown, and tan sand; brown platy sandstone; a very few gravel layers, with pebbles of rhyolite, latite and quartzite.
Yellow sand and gravel 100 Distinctive yellow to buff sand with gravel layers containing pebbles of rhyolite, quartzite, limestone, and chert.	*Tan playa deposits* 100 Buff and tan gypsiferous silt; in general sandier than underlying playa deposits.
Tan playa deposits	*Tan playa deposits*
3600 Tan and buff sand; tan, brown, and gypsiferous silt and clay; 2–20 inch irregular layers of brown cemented sandstone weathering to rounded slabs. Upper portion grades northward into buff sand with layers of gravel containing pebbles of quartzite, latite and rhyolite, and chert. Lower portion grades northward into buff, pink, and white sand and red and greenish gypsiferous silt. The few gravel layers have pebbles of rhyolite and latite, quartzite, chert, and quartz. Interbedded at Cerros Mohinos with basalt sills and flows. Sand adjacent to the sills is locally silicified to hard yellow quartzite and blue chert, and is locally permeated with limonite.	

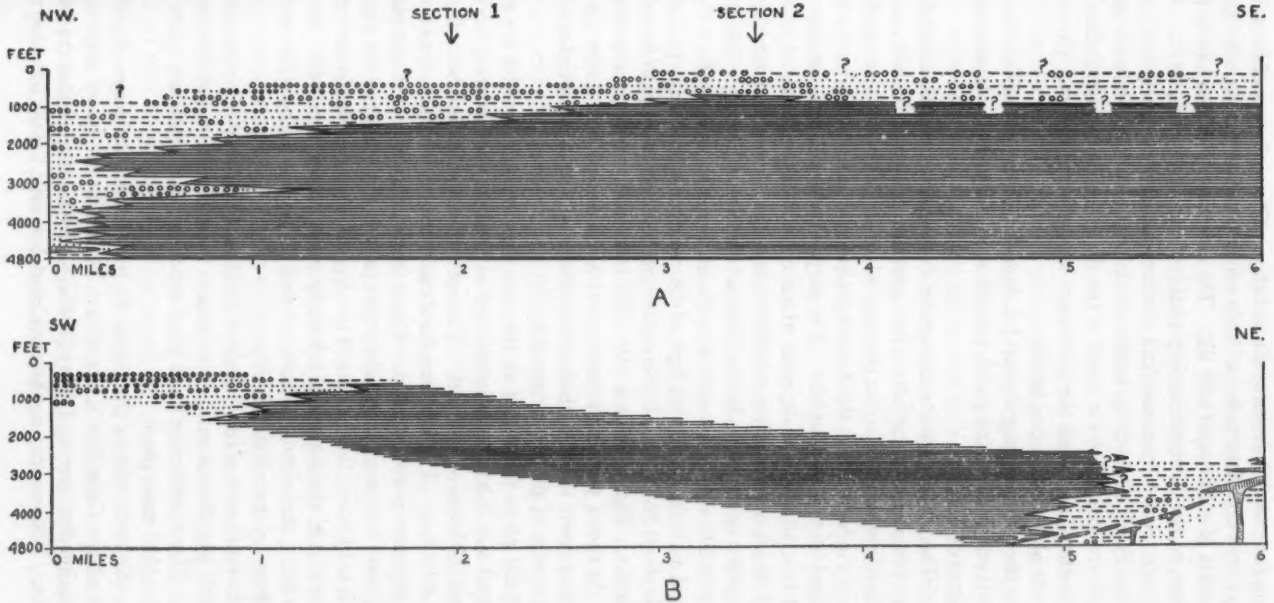

FIGURE 8.—*Diagrammatic sections of playa deposits of Gabaldon Badlands*

(A) Northwest-southeast section. All beds on west limb of Gabaldon anticline are projected into the diagram. (B) Southwest-northeast section. Dip of beds not shown. Sills and flows of Cerros Mohinos at northeast end.

cation cracks on the rounded slopes of silt and clay. Certain layers of tan sand 2-20 inches thick are cemented into resistant beds which weather into rounded slabs and stand on pedestals of softer sand and silt. The cemented portions locally transect the stratification, so the cementation is probably secondary (Pl. 7, fig. 2). Certain horizons are characterized by cannonball concretions, dark-brown limonitic concretions (Pl. 7, fig. 1), or white limy mudstone concretions. Layers with abundant gypsum crystals are conspicuous in much of the silt and clay, but no distinct beds of gypsum were found. A few of the silt layers are greenish brown. Cross-bedded aeolian sand was observed at one locality.

Compared to the interfingering aluvial-fan deposits, the playa deposits are darker (tan and red rather than buff and pink), contain more silt and clay layers, more gypsum, and less gravel.

Boundaries.—The playa deposits intergrade and interfinger with alluvial-fan deposits which contain abundant pebbles of nonbasaltic volcanics. These fan and playa deposits are therefore believed to be the equivalent of the Lower Gray and Middle Red members of the Santa Fe in the Apache graben region to the north, for these are also characterized by volcanic pebbles. The playa deposits in their thickest portion grade upward into alluvial-fan deposits which contain few pebbles of nonbasaltic volcanics, and which are therefore correlated with the Upper Buff member of the Santa Fe as exposed on the Ceja del Rio Puerco 10 miles to the east. Two diagrams have been prepared to show the known boundaries of the playa deposits. Figure 8A is a projection of all beds of the west limb of the anticline onto a plane parallel to the strike, which is about N. 20 W. It shows the northwestern and upper boundaries of the playa deposits. Figure 8B is a SW.–NE. section of the playa deposits before deformation. It shows the southwestern and northeastern boundaries for certain horizons. It also shows the sills which are interbedded with the alluvial-fan deposits on the northeast edge of the playa deposits.

The limit of the playa can be set at the zone of interfingering with fan deposits. On the northwest side it has been determined with reasonable accuracy for all horizons in the total thickness of 4100 feet. The northeastern limit has been determined for the lowest 2000 feet. The southern limit could not be determined, as the gradation into fan deposits is not exposed. There is no indication that the playa was smaller in the lower horizons than in the upper part. The extent of the playa at its time of origin is not known, for the base of the deposit is not exposed in the core of the anticline. The top of the deposit is relatively well defined, however. As the last 1000 feet was being deposited the area covered by the playa became successively restricted, at least on the northwest side.

About 4 miles northwest of the Gabaldon Badlands, on Arroyo Carrizo, more than 300 feet of dark gypsiferous sands and silts is faulted against pre-Tertiary rocks (Pl. 2, fig. 1). These beds may have beed deposited in a subsidiary playa or in a local extension of the main playa.

Correlation.—Nowhere else in the Santa Fe formation have playa deposits been found. Those of the Gabaldon Badlands are similar to the playa deposits of the Popotosa formation described by Denny (1940a) at the southern end of the Albuquerque-Belen basin. The two may not be correlated, however, for the following reasons:

(1) The Popotosa formation underlies the Santa Fe formation unconformably, whereas the playa deposits in the Gabaldon Badlands are conformable under the Upper Buff member of the Santa Fe. (2) The Popotosa formation has a tuffaceous matrix. Although the Santa Fe playa deposits have abundant pebbles of volcanic rocks, there is no tuffaceous matrix. Furthermore, the volcanic gravels may be traced into the Lower Gray and Middle Red members of the Santa Fe formation in the Apache graben region.

Mode of formation.—The playa deposits of the Gabaldon Badlands were formed in the center of a basin of interior surface drainage (*see* section on Formation of Basin Deposits). The presence of scattered gypsum crystals rather than beds of gypsum indicates that the playa was probably dry most of the time and was characterized by a water table only a few feet below the ground surface (Thompson, 1929, p. 695–696). The greenish color of some of the silt layers was caused by deposition in local pools of stagnant water (Thompson, 1929, p. 111). The presence of wind-blown sand in the playa beds and of ventifacts in the adjacent alluvial fans indicates that wind may have been a significant factor in the transportation of the playa material.

The playa covered an area of at least 15–40 square miles in the southwestern portion of the Albuquerque-Belen basin in early and middle Santa Fe time. In late Santa Fe time it was buried by the alluvial-fan deposits which were graded to the through-flowing axial river in the eastern portion of the basin. This axial river may or may not have been present in early or middle Santa Fe time. The river deposits cannot be traced directly to the lower horizons of the western fan and playa deposits, although the trace into the Upper Buff member is satisfactory.

If there were both a through-flowing river and a playa in the Albuquerque-Belen basin in early and middle Santa Fe time, then they must have been separated by a north-south drainage divide. Such a divide could have been formed either by a series of volcanic extrusions or by the accumulation of wind-blown sand, but there is no positive evidence for the existence of either of these types of barrier. It could have been formed by uparching or upfaulting along a belt now occupied approximately by the Rio Puerco valley below the Rio San Jose. If extended southward such a belt might be continuous with the broad faulted area mapped by Denny (1940a, p. 78) east of Sierra Ladron. Still farther south there were two distinct axes in the Rio Grande depression, one occupied by the Socorro playa, the other by the through-flowing river (Fig. 5).

On the other hand, the Gabaldon playa may have been the only axis of the Albuquerque-Belen basin in early and middle Santa Fe time. The playa deposits outcrop over an area of only about 15–40 square miles, but they may have been much more extensive for the southern and eastern margins are buried by Upper Santa Fe beds or Quaternary alluvium. Furthermore, the measured minimum thickness of 4100 feet for the lower and middle Santa Fe alone here indicates subsidence probably more rapid than the subsidence of the rest of the Albuquerque-Belen basin, where the maximum measured thickness for the whole Santa Fe is 2000 feet (Bryan and McCann, 1937, p. 809; Denny, 1940a, p. 93). The great thickness of playa beds may thus include sediment contributed by the whole Albuquerque-Belen basin in early and middle Santa Fe time. The structural movements at the end of this time may have

been sufficient to drain the playa and produce a through-flowing river in the eastern portion of the basin. The alluvial-fan deposits of the Upper Buff member were presumably graded directly to this river.

This latter sequence of events has some support in the meager fossil record. The age of the beds in the northern part of the Albuquerque-Belen basin and in the Española valley is Miocene or early Pliocene (Bryan and McCann, 1937, p. 806, 809). The age of the beds in the San Acacia area at the southern end of the Albuquerque-Belen basin is middle to late Pliocene (Denny, 1940a, p. 93). Thus the fan and river deposits of the southeastern part of the basin may be late Santa Fe in age, and the Gabaldon playa deposits and their associated alluvial-fan deposits may be early and middle Santa Fe.

VOLCANICS INTERBEDDED IN THE SANTA FE FORMATION

In addition to fan, playa, and axial river deposits, the Santa Fe formation contains interbedded volcanic rocks. With the exception of local patches of rhyolitic tuff related to the late Santa Fe extrusions in the Sierra de los Valles, all the volcanics are basaltic. They are associated with local volcanoes or fissures. Each covers only a few square miles at the most, although many have been reduced in area by erosion. Most are only a few tens of feet in thickness, but at the Cerros del Rio (Fig. 5, locality H), in the Santo Domingo Valley, the flows total 1200 feet (Bryan and McCann, 1937, p. 208). Within the Lower Rio Puerco area, there are at least seven separate areas of basalt interbedded in the Santa Fe formation. These areas are shown on the geologic map (Pl. 8) and also on the paleogeographic maps (Figs. 4, 5), where they are lettered A to G.

(A) Acuma Hill, west of Isleta on the Rio Grande, is an exhumed lava cone surrounded by at least 50 feet of deformed water-laid basaltic gravel overlain by 10 to 40 feet of lava, which is probably late Santa Fe. The Pueblo of Isleta is built upon the lava.

(B) Five miles west of Acuma Hill is a low, dissected, exhumed volcano consisting of a thick dome of lava which was poured out on beds of cinders. This lava is also probably late Santa Fe.

(C) On the west edge of the Llano de Albuquerque, about 5 miles southwest of the lava dome at B, is a long scarp held up by a 15-to 30-foot lava flow, interbedded in the upper Santa Fe. The same outcrops on the Ceja del Rio Puerco 2 miles to the west.

(D) Cerro Los Lunas consists of a thick volcanic neck bordered by 50–200 feet of basaltic lava overlying 50–100 feet of basaltic gravels interbedded in the upper part of the Santa Fe formation.

(E) Cerros Mohinos consists mostly of sills interbedded in the lower and middle beds of the Santa Fe formation. In the northern hill, however, there are deformed basaltic cinder beds and lava flows probably of late Santa Fe age.

(F) Just north of U. S. Highway 66 on the east side of the Rio Puerco, north of Cerro Colorado, are two small hills held up by tilted basalt flows, one of which is faulted. This basalt is interbedded in the upper or middle member of the Santa Fe formation.

(G) Gallina and Pato mesas on the Lucero uplift are capped by 100–200 feet of basaltic lava, extruded on tilted Triassic rocks. The altitudes of the mesas indicate that the erosion surface under the lava is older than the Ortiz surface, the first post-Santa Fe erosion surface recognized in this region. The erosion surface must therefore be of Santa Fe or pre-Santa Fe age. The tops of the mesas, and presumably the erosion surface beneath the lava, slope westward 100–200 feet to the mile. This slope may be primary, in which case the lava is probably of late Santa Fe age, deposited on the west flank of the Sierra Lucero (Fig. 5), or it maybe secondary, caused by the late Santa Fe or later uplift of Sierra Lucero. In this case the lava is probably early or middle Santa Fe age, as is represented in Figure 4.

LUCERO MESA

Aerial photograph of northern part of Lucero Mesa, showing long, slender landslide blocks on western edge. The gentle break in slope on the mesa in the southeast part of the picture is underlain by travertine, which crops out as well on the west edge. Landslide blocks of travertine are noticeably smaller and more closely spaced than those of basalt. Blocks slide on soft Triassic shale. Triassic sandstone beds conspicuous in southwest part of picture. Photograph from Soil Conservation Service.

FIGURE 1. LANDSLIDE CREVICE ON BASALT CAP
Northeast edge of Lucero Mesa. Crevice is about 75 feet deep.

FIGURE 2. PATCH OF TUFF (INCLINED) IN CHANNEL IN SANTA FE FORMATION
U. S. Highway 66, 1 mile west of Rio Puerco. Tuff underlain and overlain by sand and gravel of Upper Buff member of Santa Fe.

FIGURE 3. BANDED TRAVERTINE
Salt springs, Lucero fault zone.

LANDSLIDE CREVICE, TUFFACEOUS CHANNEL FILLING, AND BANDED TRAVERTINE

None of these lava flows is definitely of early or middle Santa Fe age. Most are probably late Santa Fe. The lower and middle members of the Santa Fe formation outcrop only along the western edge of the basin and are buried (if present at all) in the eastern portion of the basin. The presence of basalt pebbles in the gravels of all parts of the Santa Fe formation indicates that local basaltic extrusions occurred throughout Santa Fe time just as they have throughout post-Santa Fe time.

The extrusion of lava in different parts of the Albuquerque-Belen basin probably caused minor changes in drainage, but no major changes are indicated. If the Gabaldon playa was deposited in a sub-basin separate from the main axis of the Albuquerque-Belen basin, this sub-basin may have originated by damming lava flows. Inasmuch as the lower and middle beds of the Santa Fe formation in the critical region east of the playa are not exposed, there is no proof of any such origin.

Patches of rhyolitic tuff were found at three localities in the Lower Rio Puerco area. (1) Sec. 7, T.9 N., R.1 W., only a few hundred feet north of U. S. Highway 66, 2 miles west of the Rio Puerco. Here about 30 feet of pebbly water-laid tuff rests in a shallow channel in the buff sand and gravel of the Upper Buff member of the Santa Fe formation, and is overlain with minor unconformity by more sand and gravel (Pl. 6, fig. 2).

(2) Sec. 14, T.9 N., R.1 W., about 2 miles south of U. S. Highway 66 and 1 mile east of the Rio Puerco. Here about 75 feet of tilted cross-bedded tuff and sandy tuff rest conformably on buff and pink sand of the upper (or middle?) member of the Santa Fe.

(3) Sec. 26, T.7 N., R.1 E., at the northwest base of Cerro Los Lunas. Interbedded in the pink and buff sand of the upper (?) member of the Santa Fe formation about 60 feet below the top of the exposed section is a total of about 15 feet of water-laid sandy tuff with pellets of pumice. The conspicuous patch of tuff at the top of the exposure is of post-Santa Fe age.

AGE AND THICKNESS

Two fragments of limb bones were found in the Santa Fe formation in the Lower Rio Puerco area. One came from the Upper Buff member of the Santa Fe on the Ceja del Rio Puerco, about 9 miles north of State Highway 6. The other came from the upper portion of the playa beds in the Gabaldon Badlands. Those fossils were identified by Dr. Frank Whitmore as belonging to any of three genera of pronghorns, namely *Ramoceros*, *Plioceros*, or *Osbornoceros*, all of which are of late Tertiary age (Frick, 1937). Elsewhere in the Santa Fe formation of the Rio Grande depression the known fossils are late Miocene and Pliocene (Denny, 1940a, p. 94).

The thickest section of the Santa Fe formation in the Lower Rio Puerco area is in the Gabaldon Badlands. Here is 4100 feet of playa deposits, representing approximately the lower and middle members of the Santa Fe as defined by Bryan and McCann (1937) in the Northern Ceja area. These are overlain by at least 700 feet of alluvial-fan deposits of the upper member of the Santa Fe. The base of the section is not exposed, and the top has been removed by erosion. Therefore the whole Santa Fe was at least 4800 feet thick in this region.

This thick section was measured across the gentle western limb of the Gabaldon

anticline. The exposures are excellent, and there are enough distinctive beds so that the displacement and extent of all the faults could be determined. This situation is the reverse of that in most extensive outcrops of the Santa Fe, where abundant faulting and lack of key horizons prevent accurate measurement of thickness. Elsewhere in the Rio Grande depression the maximum thickness, 2000 feet, is in the San Acacia area (Denny, 1940a, p. 93); and the maximum estimated thickness, 4000 feet, is in the Española Valley (Denny, 1940b, p. 687).

CLIMATE OF SANTA FE TIME

The gypsiferous playa deposits representing early and middle Santa Fe time indicate an arid or semi-arid climate like the present. The occurrence of gypsum in scattered crystals rather than in massive beds indicates that the playa was characterized by a high water-table but was not occupied by a perennial lake (Thompson, 1929, p. 695–696). Wind action is demonstrated by the presence of at least one patch of cross-bedded aeolian sand within the playa beds, and of ventifacts in the near-by alluvial-fan beds.

The fossils collected in the Santa Fe formation throughout the Rio Grande depression indicate that this area supported a large and diversified fauna largely of grazing animals. The region must have had better vegetation than the sparse grass and bush cover of today, at least on the slopes and bordering highlands, and therefore more rainfall than the present 5–10 inches. An annual rainfall of 10–15 inches is not incompatible with the presence of a dry playa (rather than a lake) if most of the rain comes in the season of high evaporation. Other factors are involved in the formation of a playa (*see* section on formation of basin deposits).

One small indication of the late Santa Fe climate is the character of the slope wash which is interbedded with the upper member of the Santa Fe on the flanks of Cerro Colorado, an exhumed volcano in the middle of the Lower Rio Puerco area (Wright, 1943). This slope wash is 3–10 feet thick, whereas the modern cover of rubble is thin or absent, thus indicating a heavier vegetative cover and a more humid climate than the present.

The color of sedimentary rocks has been used as a climatic indicator. The color of the Santa Fe formation in the area studied, however, is probably controlled chiefly by two other factors: (1) the color of the source rock—the Permian, Triassic, and Jurassic rocks are mostly red, and the Cretaceous rocks are mostly buff and white; and (2) the texture of the sedimentary rock itself—wash from red silty layers at various horizons might stain a whole series of predominantly sandy beds pink or red, especially in outcrops in bluffs.

STRUCTURE

INTRODUCTION

The region now occupied by the Albuquerque-Belen basin and the highlands bordering on the west was first affected by orogenic forces in the Laramide revolution in the early Tertiary. Folds and thrust faults were formed in the Sierra Nacimiento and broad upwarps and downwarps were formed in the Colorado Plateaus. The western

FIGURE 1. CEMENTED LAYER OF BROWN SANDSTONE IN TAN PLAYA DEPOSITS
Gabaldon Badlands. Zone of cementation transects bedding. Note slabs of sandstone resting as incipient pedestals on uncemented sand and silt.

FIGURE 2. CONCRETIONS AND DESICCATION CRACKS IN SANDY SILT IN SANTA FE FORMATION
Playa deposits in Cerros Mohinos.

CONCRETIONS AND CEMENTED LAYERS IN SANTA FE PLAYA DEPOSITS

half of the Lower Rio Puerco area lies within the Colorado Plateaus. The Laramide structures are here represented by the Lucero anticline and the faulted monocline which is its extension to the north.

Erosion during early and middle Tertiary truncated these structures. In the late Tertiary downwarping and downfaulting formed the Albuquerque-Belen basin, in which the Santa Fe formation was deposited. The hinge line or fault line of this basin of subsidence probably was located along the line of weakness established in Laramide time, that is along the fault zone on the Lucero anticline and the monocline to the north. The basin deposit, however, lapped over this zone and extended several miles to the west onto the highland piedmont.

Subsidence of the depression continued apace with deposition during the late Tertiary. In late Santa Fe time, and especially in early post-Santa Fe time, accelerated subsidence of the depression and attendant uplift of portions of the bordering highlands produced the present fault border of the basin. In the Lower Rio Puerco area, as in other parts of the Rio Grande depression, this post-Santa Fe fault border is located on the east edge of the pre-Santa Fe fault zones. The Rio Grande depression is therefore smaller now than it was in the late Tertiary.

Subsequent movement in the Lower Rio Puerco area has been slight but has tilted an early Quaternary erosion surface (Ortiz pediment) and locally faulted Quarternary deposits.

Figure 9 shows the fault boundary between the Colorado Plateaus and the Albuquerque-Belen basin. The Nacimiento prong of the Southern Rocky Mountains is shown at the northern end of the map. The basin is now underlain by the Santa Fe formation, and the other regions by pre-Santa Fe rocks. Faults within the basin are also shown.

The faults are of several different ages grouped as pre-Santa Fe and post-Santa Fe (including some intra-Santa Fe). The fault border may be conveniently subdivided into four sections (Fig. 9): (1) the Naciminento section on the north, characterized by pre-Santa Fe thrust faults and post-Santa Fe normal faults; (2) the section between the Rio Salado on the north and the Rio San José on the south, consisting of a broad monocline cut by normal faults of both pre-Santa Fe and post-Santa Fe age; (3) the Lucero section, from the Rio San José to Sierra Ladron, consisting of a narrow zone of branching pre-Santa Fe faults cut by a single long post-Santa Fe fault; (4) and the San Acacia section, consisting of both pre-Santa Fe and post-Santa Fe normal faults of large displacement.

The principal faults in this long fault zone are listed in Table 2 and labeled on Figure 9.

PRE-SANTA FE DEFORMATION

Nacimiento section.—The Nacimiento uplift is an asymmetric fold cut on the west limb by the steep Nacimiento thrust fault (Renick, 1931). Pre-Cambrian granite is thrust westward a maximum of a mile over the Upper Cretaceous and older rocks of the San Juan Basin. This represents a stratigraphic throw of 3500 feet. The youngest rocks involved are the Eocene Wasatch formation, but there is evidence that uplift in this region started in latest Cretaceous times (Reeside, 1924).

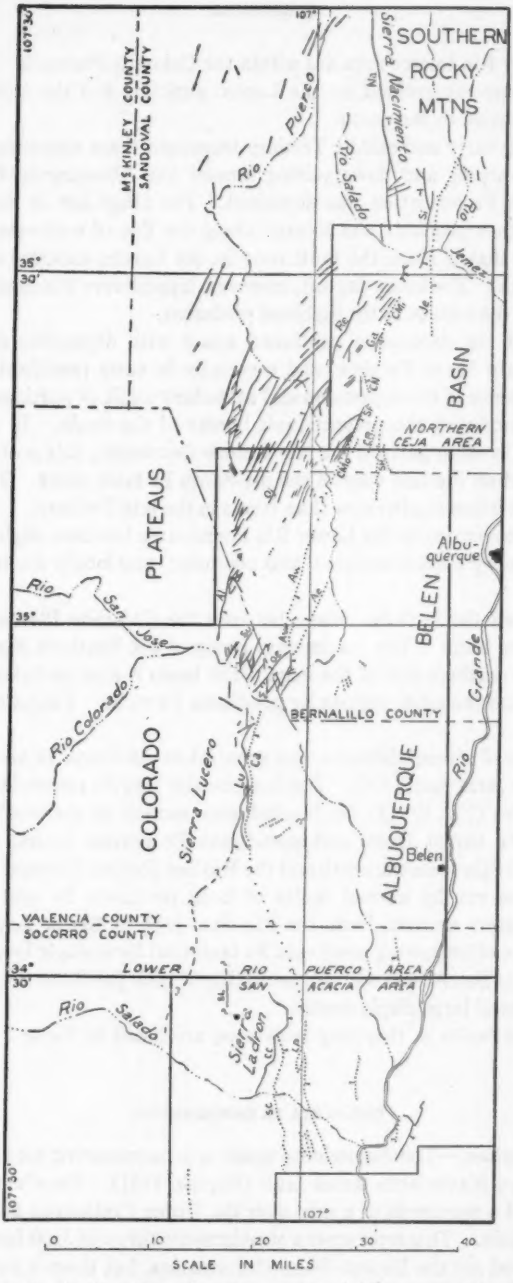

FIGURE 9.—*Fault pattern of western margin of Albuquerque-Belen basin*

Solid lines show pre-Santa Fe faults; dotted lines show post-Santa Fe (and some intra-Santa Fe) faults. For names of faults, *see* Table 2.

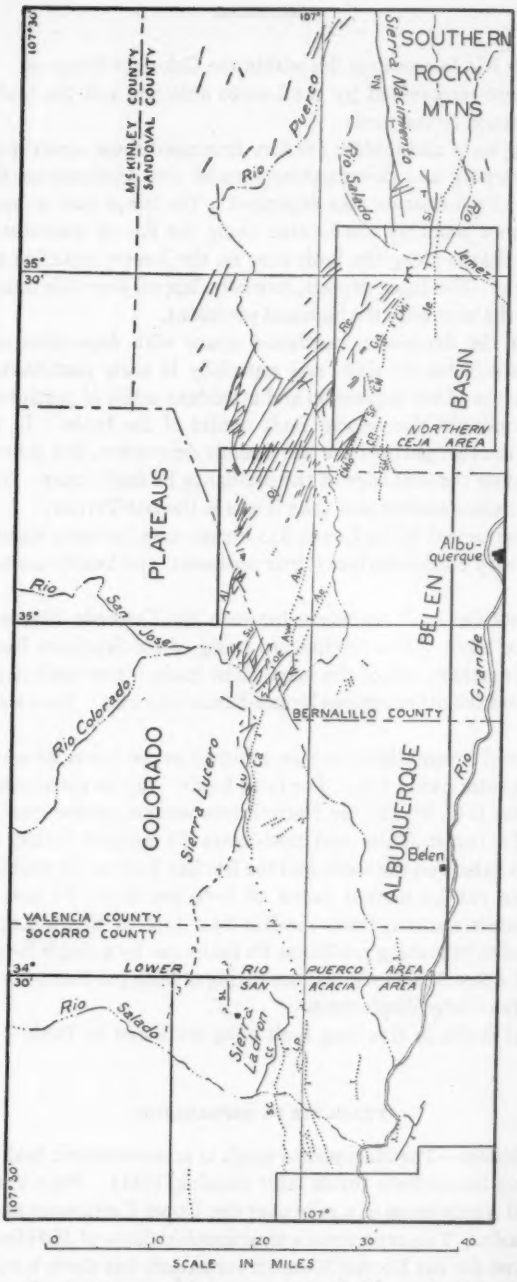

FIGURE 9.—*Fault pattern of western margin of Albuquerque-Belen basin*

Solid lines show pre-Santa Fe faults; dotted lines show post-Santa Fe (and some intra-Santa Fe) faults. For names of faults, *see* Table 2.

GEOLOGIC MAP OF THE LOWER RIO PUERCO AREA
NEW MEXICO

By H.E. Wright, 1940-41, assisted by J.W. Dow, R.C. Bryan, and G.J. Lyons

EXPLANATION

Quaternary
- Qal Qg Qgal — Alluvium and pediment gravel, shown only where older rocks are obscured.
- Qb — Basalt of several ages.
- Qtr — Travertine of several ages.
- Ti — Intrusives of several ages.

Tertiary
- Tsf Tsfb — Santa Fe formation, with interbedded basalt.
- Tmv — Miocene (?) non-basaltic volcanics.
- pT — Pre-Tertiary undifferentiated - mostly Cretaceous.

Cretaceous
- K — Dakota, Mancos, and Mesaverde formations.

Jurassic
- J — Wingate and Morrison formations.

Triassic
- Trc — Moenkopi, Shinarump, and Chinle formations.

Permian
- Cchs — Hondo and San Andres members of Chupadera formation.
- Ccy — Yeso member of Chupadera formation.
- Ca — Abo formation.

Penn.
- Cm — Magdalena limestone.

Formation contact.

Fault contact, showing dip and downthrown side.

Anticlinal axis, showing direction of plunge.

Strike and dip of beds.
- 15 Normal
- 15 Overturned
- Horizontal

Locality mentioned in text.

Town or railroad station.

Ranch.

Faults entirely in the pre-Tertiary rocks in the area north of the Rio San José taken from Hunt, 1936.

Magnetic Declination
14½° — True North — Mag. North

Scale in Miles
0 2 4 6 8

107°30' R 6 W | R 5 W | R 4 W 107°15' | R 3 W | R 2 W 107°00' | R 1 W | R E 106°45'

35°15' T 11 N | T 10 N | 35°00' | T 8 N | T 7 N | 34°45' T 6 N | T 5 N

SANDOVAL COUNTY
MONTANO
ALAMEDA
GRANT
ELENA
GALLEGOS
ATRISCO
PAJARITO
EL RITO GRANT
LAGUNA
INDIAN RESERVATION
ANTONIO GRANT
SEDILLO
ISLETA
PUEBLO GRANT
BERNALILLO COUNTY
VALENCIA COUNTY
GUTIERREZ AND SEDILLO GRANT
SAN CLEMENTE GRANT
NICOLAS DURAN CHAVEZ GRANT
BELEN
BELEN GRANT

Bonavidez Hill
Sand Hill Fault Zone
Ferro Coal Mine
Cerro Colorado
U. S. Hwy. 66
Cerro Verde
Cinder Butte
Gebaldon Anticline
Bedlands
Rio Puerco Station
Atchison Topeka & Santa Fe Ry.
State Hwy. 6
State Hwy. 85
A. Harrington
V. Harrington
Suwanee
Mesa Roseria
Oxysheer
Major
Huning
Wilson
Wils
Gallina Mesa
Cabezon Peak
Cerro del Oro
Gunn Mesa
Cow Canyon Mesa
Badger Wash
Wash Mesa
Butte Mesa
Cimarron Mesa
Arroyo Garcia
Arroyo Alamo
Arroyo Cocina
Arroyo Grabel
Arroyo Apache
Arroyo Carrizo
Arroyo Lucero
Arroyo Antonio
Arroyo José
Arroyo Colorado
Arroyo Bonito
Arroyo Oro
Arroyo Wash
Rio Puerco
Rio Grande
Rio Salado
Rio Jemez
Rio Cebolla
Rio Guadalupe
Rio Albuquerque Volcanoes
Rio Llano
Rio Cajita
Rio Blanco
Rio Cebolla
Rio Cañada
Rio Cañada Hills
Rio Cañada Mesa
Rio Cañada Coyote
Rio Cañada Comanche
Rio Cañada Solas
Rio Cañada Las
Rio Cañada Bonito
Rio Cañada Valles
Rio Cañada Mesa
Rio Cañada Cimarron
Rio Cañada Mesa
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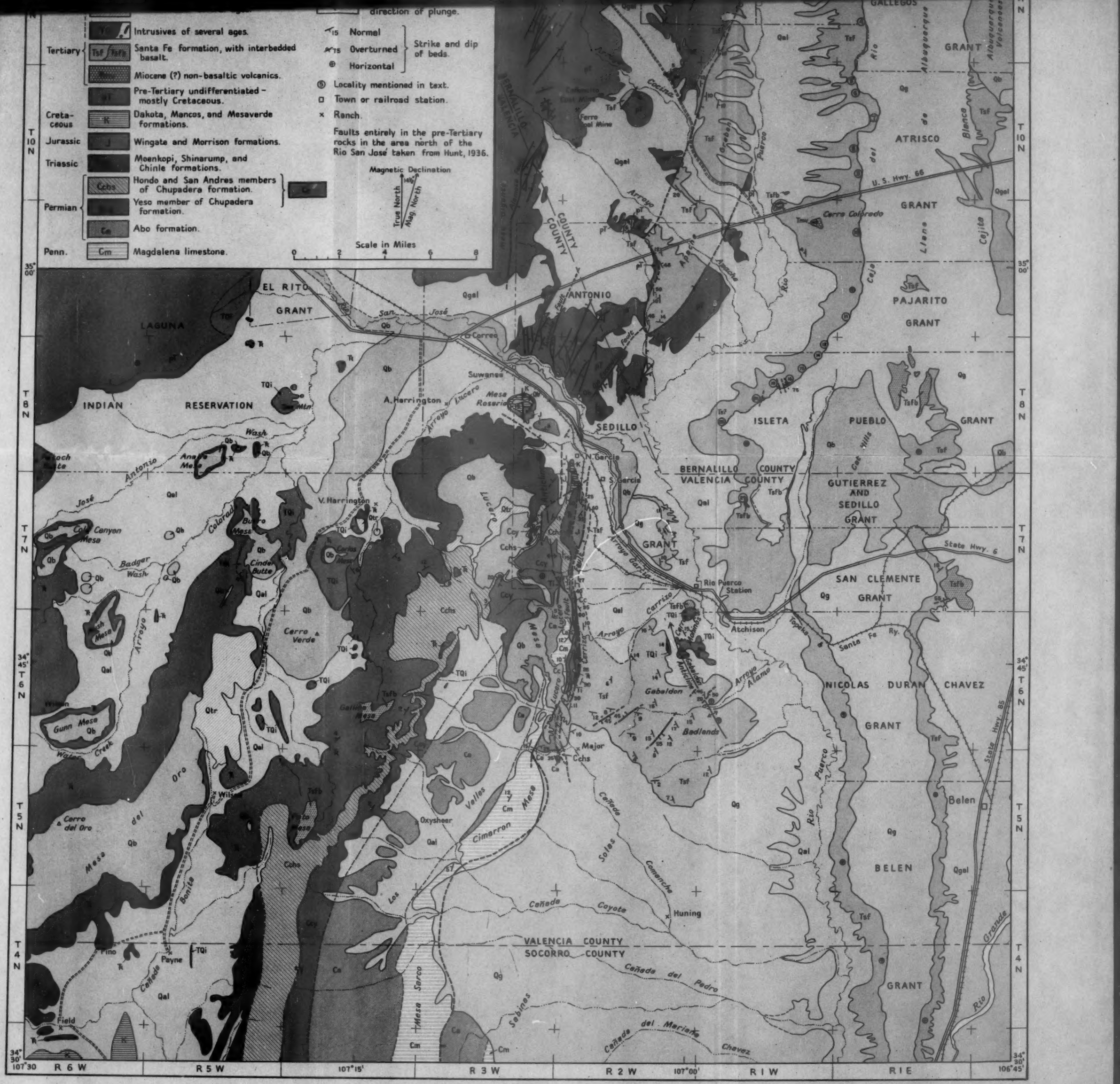
Rio Cañada Mesa



GEOLOGIC MAP OF LOWER RIO PUERCO AREA

The
Magd
Bryan

TABL

Symbol on Figure
Na
Si
Je
Je
Je
CMi
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CP
CM
SH
Ae
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Asw
Ga
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LP

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Salad

The Jemez fault in this section brings the Santa Fe formation down against the Magdalena limestone. This represents a total stratigraphic throw of 8000 feet. Bryan and McCann (1937, p. 819) point out, however, that there are two periods of

TABLE 2.—*Features of large faults in the western fault boundary of the Albuquerque-Belen basin*

Symbol on Figure 9	Name	Minimum length in miles	Maximum displacement in feet	Downthrown side	Dip	Age relative to Santa Fe
	NACIMIENTO SECTION					
Na	Nacimiento	50	3500	W (thrust)	E	Pre-
Si	Sierrita	12	2000	E (thrust)	W	Pre-
Je	Jemez (north)	10	4000–5000	E	E	Pre-
	SALADO-SAN JOSÉ SECTION					
Je	Jemez (north)	10	3000–4000	E	E	Post-
Je	Jemez (south)	10	1000	E	E	Post-
CMi	Can. las Milpas	7½	1000	E	E	Post-
CN	Can. Navajo	1½	1000	E	E	Post-
CP	Can. Pilsres	4	100	E	70° E	Post-
CM	Can. Moquino	3	1000	E	E	Post-
SH	Sand Hill	5	300	E	70° E	Post-
Ae	Apache east	10	500–1500	W	W	Post-
Aw	Apache west	10	250–500	E	E	Post-
Asw	Apache southwest	6	300–500	E	E	Post-
Ga	García	3	3000	W	W	Pre-
Re	Reservoir	7½	2000	E	E	Pre-
SF	San Fernando	7	1500	E	E	Pre-
Oj	Ojito	12	500	W	45°–50° W	Pre-
OE	Ojo Escondito	4½	3500	W	40°–70° W	Pre- Post-
Su	Suwanee	5½	1200	W	W	Pre-
Al	Alamosa	8½	2500	E	E	Pre-
	LUCERO SECTION					...
Lu	Lucero	25	2000	E	45°–80° E	Pre-
Ca	Carrizo	13	6500	E	45° E	Intra- Post-
	SAN ACACIA SECTION					...
CC	Cerro Colorado	10	several 000's	E	E	Pre-
SC	Silver Creek	13	several 000's	E	E	Intra-
LP	Loma Pelada	16	5000	E	E	Post-

deformation in the Sierra Nacimiento, and that probably only 4000 to 5000 feet of of this 8000 foot throw is pre-Santa Fe.

The third major fault in this region is the Sierrita fault, which Renick (1931, p. 74) states is probably a thrust fault with a maximum displacement of 2000 feet. Bryan states (personal communication) that this fault does not definitely cut the Santa Fe formation, as Renick's map shows. It is therefore probably one of the Laramide faults.

Salado-San José section.—Between the Rio Salado, at the southern end of the

Nacimiento uplift, and the Rio San José, a distance of about 45 miles, the pre-Santa Fe structure consists of a broad faulted monocline with downthrow on the east. The stratigraphy and structure of the pre-Santa Fe rocks of this section were studied in detail by Hunt (1936, 1938). On the geologic map (Pl. 8) all the faults in this section entirely within the pre-Santa Fe rocks are reproduced from Hunt's map.

Hunt (1936, p. 76) mapped about 250 normal faults on this monocline. The fault zone has an exposed breadth of 8 to 13 miles, but the eastern edge is probably buried under the Santa Fe formation. The average strike of these faults is N. 15° to 20° E., and the average dip is 45° to 75° W, or E.

Most of the faults are less than 2 miles long and have throws of less than 200 feet (Fig. 10). About two-thirds of the recorded faults have the west block downthrown, but the easterly dip of the beds on the monocline overcomes the effect of the faults, and the net shift of the faulted monocline is 2000 to 3000 feet down on the east.

In places most of the displacement has occurred on a single fault with downthrow on the east. Hunt describes three of these major faults, namely the Alamosa, Reservoir, and San Fernando faults. Hunt also describes several large faults with downthrow on the west side.

Hunt recognized only one period of faulting in this Salado-San José section, for he did not map the Santa Fe formation in detail. Bryan and McCann (1937) have proved, however, that both pre-Santa Fe and post-Santa Fe faults exist in the Northern Ceja area. The writer found the same relation in the Lower Rio Puerco area. The post-Santa Fe age of a fault can be proved only by its transection of the Santa Fe formation. However, the western edge of the Santa Fe formation has been removed by erosion, so that many faults entirely within areas of pre-Santa Fe rocks may be of post-Santa Fe age. On some faults there has been both pre-Santa Fe and post-Santa Fe movement. Specific instances of this relation are cited in the discussion of the post-Santa Fe movements.

Lucero section.—South of the Rio San José along the east base of Lucero Mesa the pre-Santa Fe fault structure narrows to ½–1 mile to constitute the Lucero fault zone. The actual breadth may be greater, for the eastern edge is now cut off by the post-Santa Fe Carrizo fault. The Lucero fault zone was the locus of intrusion of the Major stock. It is also marked by salt springs and travertine deposits.

LUCERO FAULT ZONE: The Lucero fault zone is located along the axis or east of the axis in the steep east limb of the asymmetric Lucero anticline (named by Darton, 1928, p. 125). The fault zone consists of from one to four curving and branching faults mostly in Carboniferous and Triassic rocks. The zone broadens at the northern end as the faults enter Jurassic and Cretaceous rocks. Toward the south only a single fault can be traced, but other faults may be buried beneath the cover of Quaternary gravel. South of Cañada Coyote (Pl. 8) this single fault was not traced, but its position is copied from Darton's reconnaissance map (1928, Pl. 26). Darton mapped the Lucero fault zone as if it were a single fault. He located it entirely within the Santa Fe rocks, entirely within the pre-Santa Fe rocks, or as separating the two. He thus did not distinguish movement of pre-Santa Fe time from that of the post-Santa Fe. The fault shown on Figure 9 as SL and located on the northwest side of Sierra Ladron had previously (Darton, 1928; Denny, 1940, p. 101) been de-

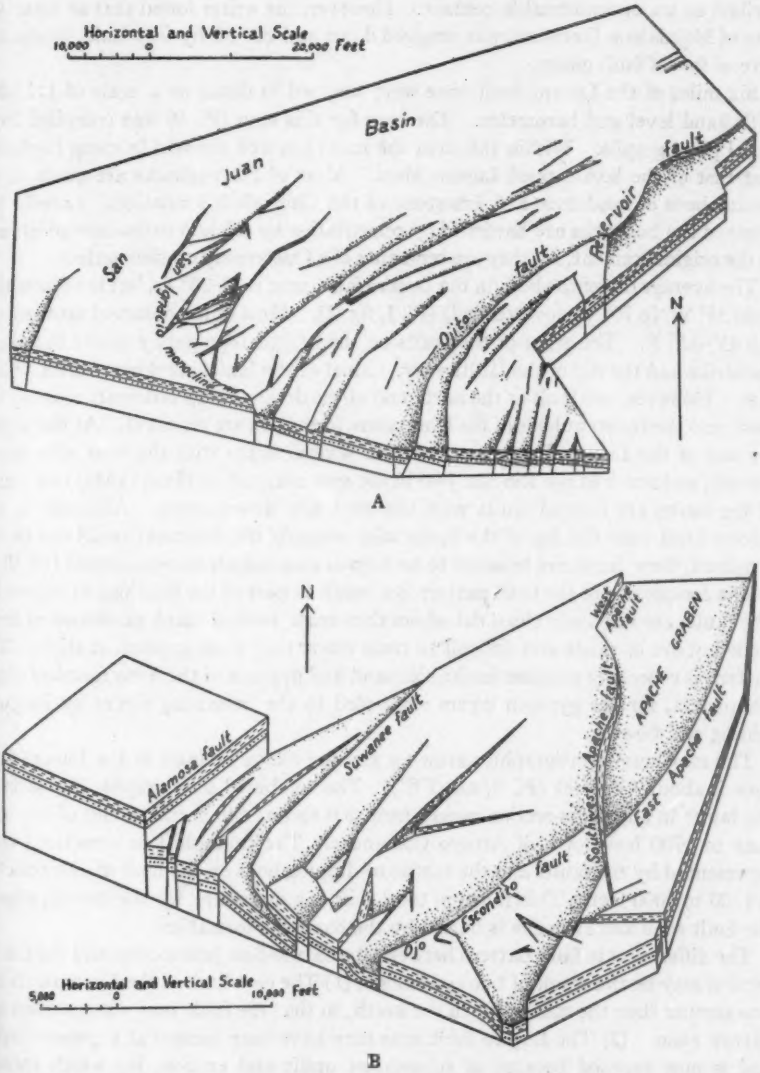

FIGURE 10.—*Block diagram of parts of Salado-San José section of border fault zone of Albuquerque-Belen basin*

A. South edge of this block is 3–5 miles south of the northern border of the Lower Rio Puerco area. (*See* Plate 9.) Although most of these faults are downthrown on the west side, the beds dip gently eastward and the net shift of the fault zone is down on the east (After Hunt, 1938, Pl. 18B).

B. Southwest edge of this block is about ½ mile north of Rio San José. Apache graben is underlain by the Santa Fe formation. Diagram extended and modified after Hunt (1938, Pl. 18A).

scribed as an unconformable contact. However, the writer found that at least 300 feet of Magdalena limestone was dragged down and cut off by this fault, producing several feet of fault gouge.

Six miles of the Lucero fault zone were mapped in detail on a scale of 1:12,000 with hand level and barometer. The base for this map (Pl. 9) was compiled from aerial photographs. Within this area the rocks are well exposed in steep hogbacks just east of the lava-capped Lucero Mesa. Most of the hogbacks are made of resistant beds of sandstone and limestone of the Chupadera formation. Locally the crests of the hogbacks are hardened by cementation by calcium carbonate additional to the original cement, for they are remnants of a Quaternary erosion surface.

The average dip of the beds in the Lucero fault zone is 15–25° E., but the dip ranges from 35° W. to 70° W. (overturned) (Pl. 1, fig. 2). Most of the observed fault planes dip 45°–55° E. The trace of the faults on the rugged topography shows that both the strike and the dip of the faults vary. Most of the faults are downthrown on the east. However, one fault at the north end of the detailed map is downthrown on the west, and the resistant beds of the Chupadera formation are repeated. At the northern end of the Lucero fault zone there are several faults with the west side downthrown, and north of the Rio San José in the area mapped by Hunt (1936) two-thirds of the faults are normal faults with the west side downthrown. Although in the Lucero fault zone the dip of the faults with westerly displacement could not be determined, these faults are believed to be normal also and are so represented (Pl. 9).

The complexity of the fault pattern is a result in part of the lithology of the rocks. The faults are relatively clean cut where they cross beds of hard sandstone or limestone but are intricate and difficult to trace where they cross gypsum or shale. The pattern is especially complex in the soft sand and gypsum of the Yeso member of the Chupadera, for the gypsum layers responded to the deforming forces by irregular folding and flowing.

The maximum stratigraphic throw on any pre-Santa Fe fault in the Lucero fault zone is about 1300 feet (Pl. 9, sec. EE′). The combined stratigraphic throw on all the faults in any cross-section ranges from 200 feet at the northern end of the fault zone to 1700 feet north of Arroyo Comanche. The total shift or structural relief represented by the faults and the eastward-dipping beds on the limb of the anticline is 1700 to 3000 feet. This range in total shift is a minimum, for the eastern edge of the fault zone and anticline is buried by the Santa Fe formation.

The differences in fault pattern between the Salado-San José section and the Lucero section may be the result of two conditions: (1) The east limb of the Lucero anticline was steeper then the monocline to the north, so that the fault zone was confined to a narrow zone. (2) The Lucero fault zone may have been formed at a greater depth, and is now exposed because of subsequent uplift and erosion, for which there is independent evidence. A restoration of the beds removed by erosion indicates that the faults of the Salado section were formed under a cover of 500 to 2000 feet, and those of the Lucero section under a cover of 3000 to 8500 feet.

MAJOR STOCK: In the southern portion of the area of detailed mapping (Pl. 9) the Lucero fault zone is intruded by the Major stock. The main portion of this body is more than a mile long and about 1500 feet broad. Sill-like extensions on the south-

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EXPLANATION

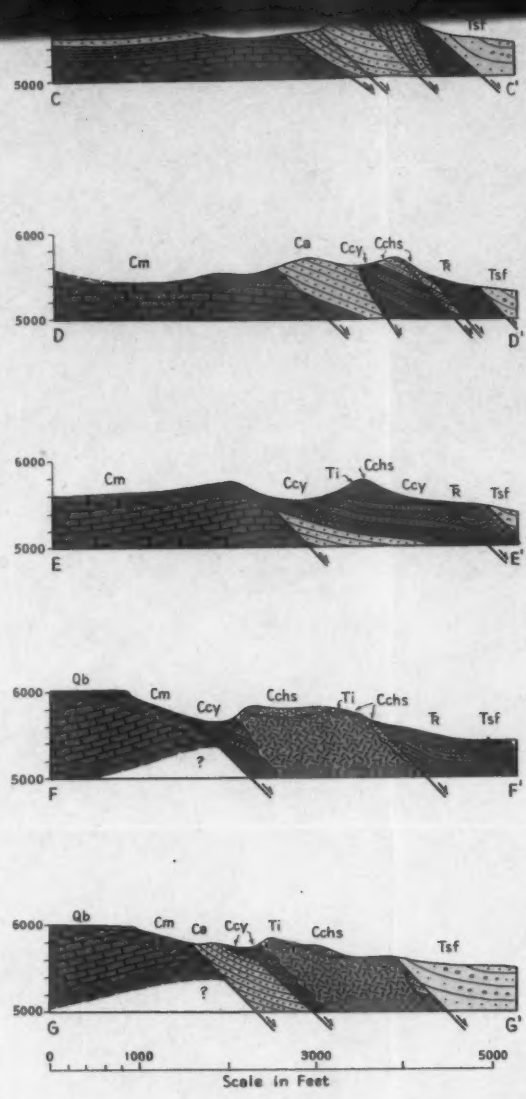
QUATERNARY	Qb	Basalt flow.
LATE TERTIARY	Tsf	Santa Fe formation.
TERTIARY	Ti	Monzonite stock.
TRIASSIC		Chinle, Shinarump, and Moenkopi formations.
PERMIAN	Ccs	San Andres member, Hondo member — Chupadera formation.
		Yeso member — Chupadera formation.
	Cc	Abo formation.
PENNSYLVANIAN	Cm	Magdalena limestone.

Fault, dashed where concealed or uncertain.

Formation contact.

25 Normal, 75 Overturned — Strike and dip of inclined beds.

E—E' Line of structure section.



EXPLANATION

QUATERNARY	Qb	Basalt flow.
LATE TERTIARY	Tsf	Santa Fe formation.
TERTIARY	Ti	Monzonite stock.
TRIASSIC	Tr	Chinle, Shinarump, and Moenkopi formations.
PERMIAN	Cchs	San Andres member, Hondo member — Chupadera formation.
	Cy	Veso member — Chupadera formation.
	Ca	Abo formation.
PENNSYLVANIAN	Cm	Magdalena limestone.

Fault, dashed where concealed or uncertain.

Formation contact.

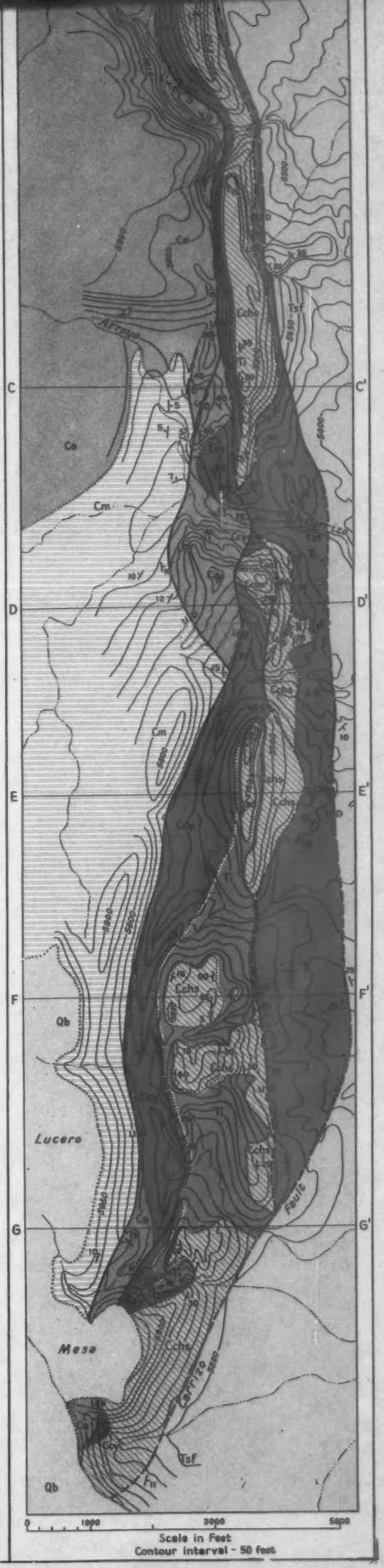
25 Normal, 75 Overturned — Strike and dip of inclined beds.

E—E' Line of structure section.

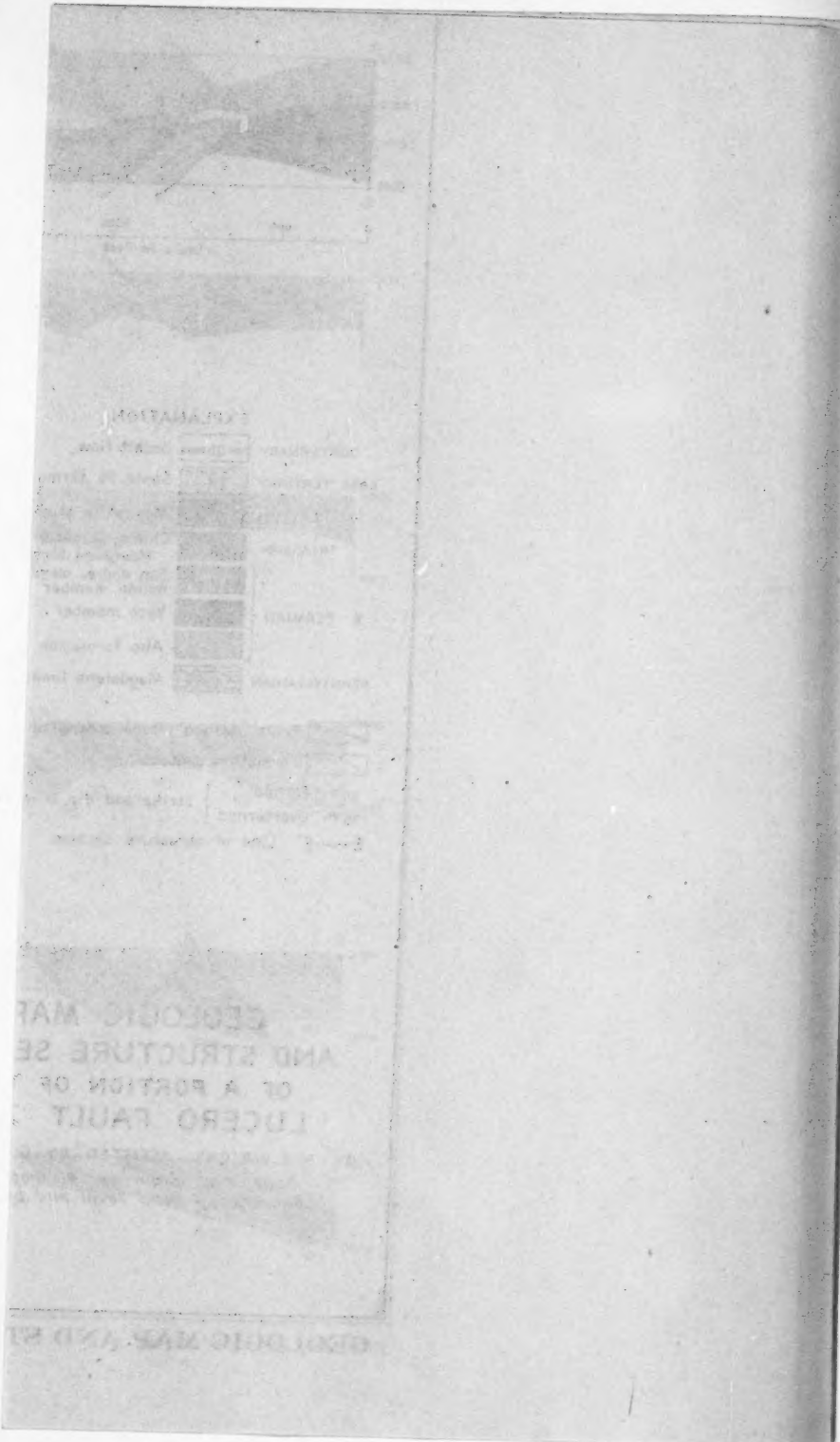
GEOLOGIC MAP AND STRUCTURE SECTIONS OF A PORTION OF THE LUCERO FAULT ZONE

BY H. E. WRIGHT, ASSISTED BY G. J. LYONS, 1941.

Base map from aerial photographs.
Contours by hand level and barometer.



GEOLOGIC MAP AND STRUCTURE SECTIONS OF LUCERO FAULT ZONE



ern and particularly the northern end make the overall length almost 3 miles. The stock is confined for the most part to the soft sand and gypsum of the Yeso member of the Chupadera formation. Silicified Hondo sandstone and San Andres limestone form roof pendants and parts of the eastern wall of the stock. Although the upper and eastern contacts are irregular in detail, the trace of these contacts on the contour map (Pl. 9) indicates an easterly dip of about 50°, roughly parallel to the average dip of the fault planes. The western contact is presumably similarly inclined. The igneous rock is in contact with the pre-Santa Fe faults only in a few places. Elsewhere there is a thin silicified band of country rock between them.

The stock probably was intruded during the movement on the Lucero fault zone. It rose up the steep east limb of the Lucero anticline, its course being controlled partly by the position of the weak Yeso sand and gypsum, and partly by the faults. Subsequent faulting was localized not at the margins of the stock itself but at the outward limit of contact metamorphism, a few tens of feet on either side of the relatively massive and resistant igneous rock.

SALT SPRINGS: Every canyon which crosses the Lucero fault zone is characterized thermal salt springs (Pl. 6, fig. 3), which are described in detail in the section on geomorphology.

San Acacia section.—Denny (1940a, p. 101–103) describes several normal faults of large displacement in the San Acacia area, two of which are pre-Santa Fe and probably helped form the basin in which the Santa Fe formation was deposited.

POST-SANTA FE DEFORMATION

Nacimiento section.—The Jemez fault, as explained above, experienced movement both in pre-Santa Fe and post-Santa Fe time. The pre-Santa Fe movement was associated with the early Tertiary thrusting in the Southern Rocky Mountains. The post-Santa Fe displacement on the part of the fault north of the Rio Salado is 3000 to 4000 feet (Bryan and McCann, 1937, p. 820) and was related to the late Tertiary subsidence of the Rio Grande depression. Although the forces which generated these two movements were different, the crustal weaknesses established in the early Tertiary localized the late Tertiary faults.

Salado-San José section.—Bryan and McCann (1937) describe six major post-Santa Fe faults or fault zones in the Northern Ceja area. Each has a stratigraphic throw of 100 to 1000 feet down on the east side.

The easternmost of these faults, the Sand Hill zone, was traced by the writer for about 5 miles into the Lower Rio Puerco area. As explained later there have been three periods of movement on this fault zone, namely late Santa Fe, post-Santa Fe, and late Ortiz.

The other post-Santa Fe faults of the Northern Ceja area disappear southward under the alluvium of the Rio Puerco valley. However, south-southwestward along the strike of the Cañada Moquino fault is the post-Santa Fe fault which bounds the Apache graben on the west, and the two are probably continuous.

The Apache graben lies within the area mapped by Hunt (1936; 1938). However, Hunt did not attempt to distinguish any structure in the Santa Fe formation. He mapped all post-Cretaceous material as one unit resting unconformably on the

Cretaceous rocks. He thus confused the Santa Fe formation, dissected Quaternary gravel covers, recent alluvium, and soil. The Apache graben is at least 12 miles long and about 3 miles wide. It is bounded on the west and east by single faults which strike about N. 20° E. On the southwest end is a curving fault that strikes N. 30° W. to N. 20° E.

The amount of displacement on the Apache graben faults is difficult to determine because of the indistinct horizons of the Santa Fe formation in this area. West of the west Apache fault lie detached patches of the Lower Gray member of the Santa Fe formation which rest unconformably on Cretaceous rocks. On the east side of this fault is the Middle Red member. The stratigraphic throw is the thickness of the Lower Gray member, which in this area is at least 250 feet. West of the east Apache fault lies the Upper Buff member of the Santa Fe, or, at the southern end, the Middle Red member; on the east lie Cretaceous rocks. The maximum stratigraphic throw is the thickness of the Lower Gray, the Middle Red, and part of the Upper Buff, an estimated 1500 feet. On the southwest Apache fault the Middle Red member is faulted against Cretaceous rocks, and the estimated stratigraphic throw is 300 to 500 feet. The beds of the Santa Fe formation in the Apache graben are gently dipping except near the faults. The total average vertical displacement in the graben is about 500 to 1000 feet.

The westernmost outcrop of the Santa Fe formation in the Salado-San José section is about 3 miles west of the Apache graben, in T. 10 N., R. 2 W. There a small patch of the Lower Gray member, dipping 6° E., is probably faulted against Cretaceous rocks on the west side and overlies them unconformably elsewhere.

The presence of faulted patches of Santa Fe formation throughout the region mapped by Hunt introduces the problem of the date of the faulting. The Santa Fe formation rests unconformably on Cretaceous rocks and is itself faulted. Therefore there have been two periods of deformation. Within the area of Cretaceous rocks the faults are post-Cretaceous and presumably mostly Laramide, but some may be post-Santa Fe. Erosion has removed most of the Santa Fe formation from this region, and therewith the only sure evidence for dating.

The "pre-Santa Fe" faults curve, branch, and cut off one another. Some even displace others several hundreds of feet, but all such faults may represent the same general period of deformation. One example, however, of suggested double movement on one fault is at the southern end of the Apache graben. The relations are shown on a block diagram (Fig. 10B) modified from Hunt (1938, Pl. 18A). In this locality the southwest Apache fault is apparently continuous with a north-south fault mapped by Hunt and labeled "Minimum displacement 1000 feet." The southwest Apache fault thus extended apparently displaces a northeast-trending fault, dividing it into a northern portion (the east Apache fault) and a southern portion (the Ojo Escondito fault). Calculations show that the lateral displacement of about 2000 feet indicated on the map could be produced by a throw of 1000 feet (as suggested by Hunt's label) on an oblique fault dipping 45° to 60° E.

There has certainly been movement on these faults in post-Santa Fe time, for they cut the Santa Fe formation. However, there was probably also movement in pre-Santa Fe time, as is indicated by the following relations. The total displacement on

the Ojo Escondito fault increases to the north and is 3500 feet where the fault passes under the Santa Fe formation (Hunt, 1938, p. 76). The total displacement on the east Apache fault, which is the northward continuation of the Ojo Escondito fault, is estimated to be only 500 to 1500 feet. It is certainly less than 3500 feet. Therefore there must have been two periods of movement on the Ojo Escondito-east Apache fault, one pre-Santa Fe, the other post-Santa Fe.

Bryan and McCann (1937, p. 826–827) make three main distinctions between the "pre-Santa Fe" and the post-Santa Fe faults in the Northern Ceja area. They state that the post-Santa Fe faults have an average north-south trend, are downthrown on the east side, and have large displacement; and that the pre-Santa Fe faults have an average northeast trend, are downthrown mostly on the west side, and have small displacement.

These distinctions are not conclusive in a detailed consideration of the faults of the Apache graben region in the Lower Rio Puerco area, in the following respects.

(1) The trend of the east and west Apache faults is essentially parallel to the average trend of the pre-Santa Fe faults.

(2) The west Apache and the southwest Apache faults have the east side downthrown. In this way they resemble the post-Santa Fe faults of the Northern Ceja area, but they also resemble about 35 per cent of the "pre-Santa Fe" faults, including such large faults as the Alamosa and Reservoir. Furthermore, the east Apache fault has a large (500 to 1500 feet) downthrow on the west, like the remaining 65 per cent of the "pre-Santa Fe" faults. For the whole Salado-San José section, however, the generalization is justified that most "pre-Santa Fe" faults are downthrown on the west side and most post-Santa Fe faults are downthrown on the east.

(3) The maximum displacement for "pre-Santa Fe" faults with the west side downthrown is 3500 feet; for those with the east side downthrown 2500 feet. The net shift or total structural relief on the whole "pre-Santa Fe" fault zone and monocline is 100 to 2500 feet. This figure does not take into account the probable eastward extension of the zone under the Santa Fe formation, but it probably includes an indeterminable amount of post-Santa Fe movement. The amount of displacement on the Apache graben faults is estimated to be 200 to 1500 feet, or considerably less than the maximum on the "pre-Santa Fe" faults.

(4) Finally, as above intimated, many of the so-called pre-Santa Fe faults, *i.e.* those faults entirely within the Cretaceous rocks, may be of post-Santa Fe age, at least in part. Such are the Ojo Escondito fault and the northern parts of the Jemez and the San Fernando faults (Bryan and McCann, 1937, p. 822).

Thus no individual fault in this zone can be dated as pre-Santa Fe or post-Santa Fe merely on the basis of its trend and the direction and amount of its displacement. However, there were certainly two periods of deformation. The formation of the faulted monocline in this section was probably related to the early Tertiary warping of the Colorado Plateaus (Bryan and McCann, 1937, p. 827). Hunt (1938, p. 78) shows by calculations on cross sections that the "pre-Santa Fe" faults have produced a net widening of 3 or 4 per cent. Whether the forces at depth were compressional or tensional, the surface expression is certainly tensional. The distinctive fault pattern of this zone displays three features produced experimentally in a graben by

Cloos (1936, Figs. 215, 218), namely the eastward-dipping beds, the synthetic (eastward-dipping) faults, and the antithetic (westward-dipping) faults. The distinct en echelon plan of the fault zone may be related to horizontal shearing at depth (Fath, 1920, p. 79).

The pre-Santa Fe faults may be associated with the early stages of subsidence of the Rio Grande depression in the middle Tertiary, rather than with the Laramide orogeny in the early Tertiary. If this be true, the difference in pattern, particularly the abundance of antithetic faults in the pre-Santa Fe group, may be a result of differences in lithology of the rock involved. The pre-Santa Fe faults are in the interbedded competent sandstone and soft shale of the Mesaverde and Mancos formations. The post-Santa Fe faults, which are mostly synthetic, cut unconsolidated sand and gravel and silt.

However, the faulted Cretaceous rocks are overlain unconformably by the Lower Gray member of the Santa Fe formation, and 2000 to 3000 feet of Upper Cretaceous rocks had been removed during the time represented by the unconformity. Probably, therefore, most of the pre-Santa Fe faulting long antedated Santa Fe deposition and was thus of early Tertiary (Laramide) age rather than of middle Tertiary age.

The post-Santa Fe faults in the Salado-San José section, however, are definitely associated with subsidence of the Rio Grande depression, a typical Basin and Range structure with the line of faulting following closely the zone of weakness established by the pre-Santa Fe faulting.

Lucero section.—Post-Santa Fe deformation in the Lucero section was concentrated along the Carrizo fault. This structure can be traced as a single curving fault for 12 miles from the Rio San José to the Arroyo Comanche (Pl. 9). It probably continues southward under the gravel of Sabinas Solas to join the Loma Pelada fault in the San Acacia area (Fig. 9). The Carrizo fault separates the Santa Fe formation on the east from the pre-Santa Fe rocks of the Lucero fault zone on the west (Pl. 2, fig. 1).

The stratigraphic throw on the Carrizo fault is best measured near Arroyo Comanche. Here uppermost beds of the Santa Fe formation are faulted against the Abo formation. The base of the Santa Fe on the east side of the fault is at a depth of at least 4800 feet, which is the approximate thickness of the Santa Fe in this region. On the west side of the fault the Santa Fe formation, represented by the basalt flows of Pato and Gallina mesas, rests on the upper beds of the Triassic rocks, about 1590 feet stratigraphically above the Abo formation. The total stratigraphic throw is thus about 6300 feet. The throw is probably large also to the south, where the Santa Fe is probably faulted against the Magdalena formation. To the north, however, the throw decreases, as younger and younger pre-Tertiary formations are in contact with lower horizons in the Santa Fe formation. The fault probably dies out completely near the Rio San José.

The post-Santa Fe Carrizo fault differs from the pre-Santa Fe faults of the Lucero zone in the following respects:

(1) The Carrizo fault is a long continuous fault which cuts off several of the pre-Santa Fe faults. Most of the faults of the Lucero zone curve, branch, and die out rather than cut one another.

(2) The Carrizo fault has a consistent dip of about 45°E., as far as could be determined, and is downthrown on the east side. Although most of the faults of the Lucero zone dip 45° to 80° E. and are downthrown on the east side, several are downthrown on the west side.

(3) The Carrizo fault apparently cuts off the edge of the Major stock, which is of pre-Santa Fe age, as is indicated by the presence of pebbles of monzonite in the Santa Fe formation just to the east. The stock, however, is intimately associated with the fault of the Lucero zone and was probably intruded during the pre-Santa Fe faulting.

(4) The maximum stratigraphic throw on any one fault of the Lucero zone is 1300 feet, and the whole Lucero fault zone 1700 feet. The maximum stratigraphic shift or structural relief on the fault zone and the east limb of the anticline is 3000 feet. None of these measurements is as large as the maximum stratigraphic throw on the single Carrizo fault, *i.e.*, 6300 feet. It is possible that the pre-Santa Fe fault zone extends eastward and is now buried by the Santa Fe formation, and that the post-Santa Fe fault cuts through the middle of this zone rather than the east edge of it, but there is no positive evidence for this.

Movement on the Carrizo fault commenced in late Santa Fe time. The coarsening of the alluvial-fan material in the upper beds of the Santa Fe formation in this region indicates that the Lucero anticline was rising. It was probably uplifted along the Carrizo fault, at the western edge of the Gabaldon playa. Spring activity was associated with this renewed uplift, and the springs supplied calcium carbonate and pebbles of travertine to the upper beds of the Santa Fe formation.

San Acacia section.—The principal post-Santa Fe fault in the San Acacia area is the Loma Pelada fault, which separates the Santa Fe formation from the mid-Tertiary volcanics east of Sierra Ladron (Denny, 1940a, p. 103). It has an estimated throw of 5000 feet down on the east and probably extends northward under the gravel cover of Sabinas Solas to merge with the Carrizo fault of the Lucero section. The Silver Creek fault, a few miles west of the Loma Pelada fault, was active during Santa Fe time and maintained highlands to the west which supplied gravel to the Santa Fe formation.

Most of the observed faults in the San Acacia area are apparently related to the subsidence of the Rio Grande depression. Miocene faulting produced a preliminary enclosed basin in which the Popotosa formation was deposited. Late Miocene and Pliocene faulting deformed these beds and initiated and maintained the basin in which the Santa Fe formation was deposited. Post-Santa Fe subsidence along the Loma Pelada fault has more sharply delimited this basin.

DEFORMATION WITHIN THE BASIN

Gabaldon anticline.—The Gabaldon anticline is one of the few large folds ever found in the Santa Fe formation. Its axis trends N. 20° W. through the west edge of Cerros Mohinos and plunges gently northward. The anticline is bordered on the west by a narrow syncline produced by drag on the Carrizo fault. The west limb has a breadth of 5 miles and an exposed length of 8 miles. The beds on the west limb have a uniform dip of 10° to 15° and provide a section of 4800 feet of Santa Fe formation, the thickest ever measured in the Santa Fe (Pl. 4, fig. 1). Most of the east limb is buried

under the alluvium of the Rio Puerco Valley. The northeast portion, however, is exposed in Cerros Mohinos, where sills and flows are interbedded with the alluvial-fan and playa beds of the Santa Fe formation. The sills have an average dip of 15° E., the sand and silt beds 25° to 35° E.

Four cross faults were located on the west limb of the Gabaldon anticline. The two northern faults trend N. 55° E. and form a small graben with a throw of about 300 feet. The third fault is much larger; it drops the alluvial sand and gravel of the upper Santa Fe 1500 feet down on the southeast opposite tan playa deposits. It may be traced for almost 2 miles across the Badlands and is probably continuous with a small fault noted 1 mile still farther northeast. Southeast of this small continuation is the fourth fault of the Badlands. It is exposed for only a few hundred feet but is remarkable in that it has two sharp bends, one of 40°, the other of 55°. The bent fault plane is marked by a sand dike, as are many of the faults in the Santa Fe (Pl. 2, fig. 2; Pl. 3, fig. 1). The sand dikes are normally 6 inches to 3 feet thick. They are composed of sand and gravel loosened from the wall rock and thoroughly recemented with calcium carbonate. They consequently stand up as small ridges and serve admirably to locate faults.

The Gabaldon anticline was probably formed by localized compression along the margins of the Rio Grande depression. The compression was caused presumably by the diminution in cross-sectional area of the graben as it subsided 6300 feet along the Carrizo fault. Similar, though much smaller, folds were found by Bryan and McCann (1937, p. 823) in areas between the post-Santa Fe faults of the Northern Ceja area; and by Hunt (1938, p. 77) adjacent to the Ojo Escondito fault, which is in part of the post-Santa Fe age.

Sand Hill fault zone.—The Sand Hill fault zone is located on the Ceja del Rio Puerco at the northern edge of the Lower Rio Puerco area. It was mapped in part by Bryan and McCann (1937). Although it is associated with the border faults of the Albuquerque-Belen basin, its complex history deserves special mention.

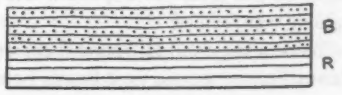
The Sand Hill fault zone consists of two groups of faults. The western group may be traced for 7 miles from north to south and consists of five en echelon faults, each marked by a sand dike. The northernmost of this group has two strong bends, one of them almost 90°. Along this chain of faults the Upper Buff member of the Santa Fe formation on the east abuts against the Middle Red member on the west. Near the most northerly fault of the group the Upper Buff member has a small angular unconformity in its upper part (Pl. 3, fig. 1). The discordance in bedding disappears within a few hundred feet to the north, east, and south.

The development of the Sand Hill fault zone is presented diagrammatically in a series of cross sections in Figure 11. Movement in late Santa Fe time on the western group of faults produced the gentle drag fold in the beds in the adjacent eastern block. Subsequent erosion and deposition resulted in the angular unconformity. Post-Santa Fe movement on the same western Sand Hill faults displaced the new upper beds.

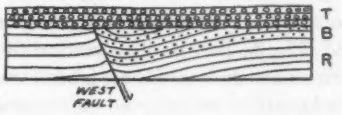
The eastern of the two groups of faults in the Sand Hill zone is 500 to 3000 feet east of the northern fault of the en echelon chain. It has an average trend of N. 20° W. and may be traced for 1½ miles across several spurs of the scarp, disappearing under

the cover of the Llano. The Upper Buff member of the Santa Fe formation lies west of the fault (Pl. 3, figs. 2, 3). On the east or downthrown side there is about 150 feet of calichified sand and gravel. The fault itself is overlain by the usual 10 feet of

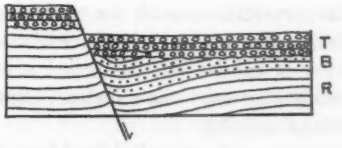
1. Deposition of Middle Red member (R) and most of Upper Buff member (B) of Santa Fe formation.



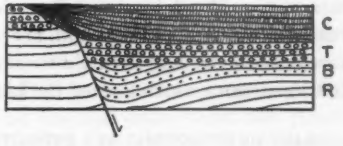
2. Faulting on west fault of Sand Hill zone. Erosion. Deposition of tan sand and gravel (T) of Upper Buff member of Santa Fe formation.



3. Renewed movement on west fault, producing local depression.



4. Recession of fault scarp. Deposition and calichification of sand and gravel (C) deposited in the depression by streams and wind.



5. Faulting on east fault of Sand Hill zone. Erosion. Calichification of the whole erosion surface.

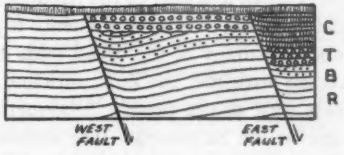


FIGURE 11.—*Development of Sand Hill fault zone*
North end of Lower Rio Puerco area.

caliche characteristic of the whole Llano de Albuquerque and developed in the early Pleistocene during the formation of the Ortiz pediment, of which the Llano is a remnant. This local thickening of the caliche cover may represent local downfaulting during the development of the Ortiz pediment. (*See* Figure 11.) In the

depression thus formed, sand and gravel accumulated and were calichified. The lowering proceeded in steps, for there are at least 19 distinct horizons of caliche in the 150 feet, each separated by horizons containing less caliche. Finally, when movement on the fault ceased, the whole area was stable, and a 10 foot layer of massive caliche was formed.

Thus in the Sand Hill zone there were three distinct periods of movement—one late Santa Fe, the second post Santa Fe and pre-Ortiz, the third late Ortiz. A few miles to the west are the border faults of the basin, on which there were still other movements, namely early Tertiary (Laramide) and perhaps middle Tertiary.

Other faults.—On the Ceja del Rio Puerco about half way between U. S. Highway 66 and State Highway 6 are five small faults which have an average strike of N. 15° Wi (Fig. 6; Pl. 8). The vertical displacement on each fault is only about 20 feet. Movement on two of these faults commenced before the end of deposition of the Santa Fe formation as indicated by the absence of the tan silt bed in the block between the two faults (Fig. 6, column 18). Evidently this block was raised up, the tan silt was eroded off, and gravel was deposited on top of the underlying buff and pink sand. Later movement on all the faults displaced the gravel. During the formation of the Ortiz pediment in the early Pleistocene, the deformed gravels were eroded, and a layer of caliche was developed across the top. Final movement on these faults locally displaced the caliche. Continued erosion and calichification restored the caliche capping.

At the southern end of the Llano de Albuquerque, Denny (1941) found two post-Ortiz faults, one displacing the entire thickness of caliche, the other (Recent) at the base of the Magdalena and Bear Mountains. The late faults in the Lower Rio Puerco area, on the other hand, are of Ortiz age because they are overlain by caliche developed during late Ortiz time which, in this region, ended when the southeastward-flowing streams which formed the Llano were captured by the Rio Puerco.

SUMMARY OF STRUCTURAL AND DEPOSITIONAL HISTORY OF THE ALBUQUERQUE-BELEN BASIN

During the Laramide orogeny there was folding and thrust faulting in the Sierra Nacimiento (Renick, 1931) and in the Los Pinos Mountains (Stark and Dapples, 1941) north and east of the Albuquerque-Belen basin respectively. The date of the folding in the Sierra Naciminento is post-Wasatch (Eocene). The Laramide folding produced many of the broad folds and monoclines of the Colorado Plateaus. The Lucero anticline, the Zuñi anticline, and the San Juan Basin are three such broad folds west of the present Albuquerque Belen basin. The eastward-dipping monocline in the Salado-San José section, between the Lucero anticline and the Nacimiento uplift, was probably formed and faulted at this time.

The highlands formed by the Laramide movements were eroded throughout the early and middle Tertiary. At least 5000 feet of Mesozoic rocks was removed from the Lucero anticline, and 2000 to 3000 feet from its northward monoclinal extension. Remnants of Eocene and Oligocene terrestrial deposits in portions of the Rio Grande depression (Darton, 1928, p. 56; Stearns, 1943; Smith, 1938; Dunham, 1935) indicate that there was at least local sedimentation during the early Tertiary. Vulcanism, which had been active in southern Colorado (Reeside, 1924) and in southern New

Mexico (Lasky, 1938) since the Cretaceous, reached a climax in the middle Tertiary, and great piles of andesite, latite, rhyolite, and trachyte were constructed in many areas of the Southwest. The largest volcanic areas near the Albuquerque-Belen basin were the Sierra de los Valles to the north, Mount Taylor to the west, and the Datil-Mogollon area to the southwest. After the main floods of lava, but presumably within the middle Tertiary period of vulcanism, preliminary basins of deposition took form and received tuffaceous sediment from the volcanics as well as nonvolcanic sediment from older rocks. Such basin deposits are the Popotosa formation (Denny, 1940a), the Picuris tuff (Cabot, 1938), and presumably also the Abiquiu tuff (Smith, 1938).

By the late Miocene the volcanic activity had subsided, and the main outlines of the Rio Grande depression were being formed. The Albuquerque-Belen basin, one of the subdivisions of the Rio Grande depression, subsided by downwarping and downfaulting. The eastern edge of the basin was probably somewhere near the base of the present Sandia, Manzano, and Los Pinos Mountains. The western hinge line of the basin was probably located along the line of the Lucero fault zone and the monocline to the north, a line of weakness established during the early Tertiary period of deformation. Some of the faults in the monocline may have been formed in the early stages of the subsidence of the basin.

The Santa Fe formation, however, lapped over this hinge line and onto the plateau province to the west. The absence of coarse gravels in the lower and middle members of the Santa Fe along the western margin of the basin indicates that there were no rugged highlands near by and therefore no high fault scarps. Rather, subsidence at this time on the west side of the basin was a slow process of downwarping. The axis of maximum subsidence was in the southwestern part of the basin. Here was formed the Gabaldon playa in which was deposited about 4000 feet of gypsiferous sand, silt, and clay received from the Mount Taylor and Datil-Mogollon volcanic fields and the Zuñi uplift to the west, and to a less extent from the San Juan Basin and Jemez Mountains to the northwest and north. The playa probably lapped over onto the truncated Lucero anticline.

Very little is known of the eastern part of the Albuquerque-Belen basin during early and middle Santa Fe time. Wells drilled in the Rio Grande valley show only 1700 feet of beds. Possibly this part of the basin did not not subside so rapidly as the part in which the playa beds were deposited. It either drained into the Gabaldon playa or supported an axial river which flowed southward out of the basin.

In late Santa Fe time, however, the rate of uplift of the bordering highlands was accelerated. The alluvial-fan deposits around the whole western margin of the basin became coarser as stream gradients were increased. Uplift of the highlands to the north brought pebbles of nonbasaltic volcanics from the Sierra de los Valles and pebbles of quartzite, chert, quartz, and granite from the Sierra Nacimiento. Contemporaneous uplift of Sierra Ladron on the south permitted continued supply of coarse gravel for the Santa Fe fans. Renewed uplift of the Lucero anticline athwart the western edge of the Gabaldon playa allowed erosion to strip away the edges of the playa deposits from the new highland and cut into Triassic and Carboniferous rocks. Pebbles from these older formations were deposited in coarse alluvial fans at the east-

ern base of the new highland. Spring activity along the Lucero fault zone resulted in the addition of travertine pebbles to the fan gravel as well as calcium carbonate for cement.

The alluvial-fan deposits of the upper member of the Santa Fe formation buried the playa deposits. They were graded to a through-flowing axial river which occupied the eastern portion of the Albuquerque-Belen basin. This river connected most of the basins of the Rio Grande depression in late Santa Fe time and may be considered an ancestral Rio Grande. It left the Albuquerque-Belen basin through a gap on the southeast edge now occupied by the Los Pinos Mountains. It probably returned to the main axis of the depression some miles to the south. The portion of the depression thus circumvented by this axial river was the Socorro basin, which was occupied by a playa during all or part of Santa Fe time.

The accelerated subsidence in late Santa Fe time, inferred from the coarsening of alluvial-fan deposits, is indicated directly on a smaller scale by the presence of faults on which there was movement before the end of deposition of the Santa Fe formation. The deformation did not reach a climax, however, until the end of Santa Fe time. Then major normal faults were formed around the edges of the basin. The throw on these faults varies from a few hundred feet to 6300 feet. This maximum figure was measured on the Carrizo fault in the Lower Rio Puerco area and probably includes much of the movement during Santa Fe time.

These boundary faults in most cases are inside the margin of the basin of deposition and inside the zone of pre-Santa Fe faulting. In the San Acacia area the Loma Pelada fault is 3 miles east of the intra-Santa Fe Silver Creek fault and 4 miles east of the pre-Santa Fe Cerro Colorado fault. In the Lucero section the post-Santa Fe fault is along the eastern edge of the pre-Santa Fe Lucero fault zone. In the Salado-San José section to the north the known post-Santa Fe faults are generally parallel to, but east of, the known and supposed pre-Santa Fe faults. The crustal weaknesses established by the pre-Santa Fe faulting were roughly followed by the post-Santa Fe faults. In the Nacimiento section still farther north, the individual post-Santa Fe faults, such as the Jemez fault, are parallel to the older structures, but the fault zone boundary of the depression cuts obliquely northeastward across the axis of the Nacimiento uplift and the presumed folded structures under the volcanic cover of the Sierra de los Valles. It then trends northward into Colorado, regardless of the curving trends of the Rocky Mountain fold axes.

The distinction between the pre-Santa Fe and post-Santa Fe structures in the Rocky mountain region is not obscure. The pre-Santa Fe structures are mostly compressional folds and thrusts, with local normal faulting, formed in late Cretaceous and early Tertiary. The post-Santa Fe structures are normal faults which trend across the Laramide fold axes.

South and west of the Southern Rocky Mountains, however, the Laramide structures consist of broad upwarps and downwarps separated by monoclines which may or may not be faulted. The middle and late Tertiary Basin and Range structures consist of basin blocks and mountain blocks separated by monoclines which also may or may not be faulted. The ultimate forces at depth which produced the Laramide structures were probably tangential compressional. Those which produced the

Basin and Range structures were probably vertical. However, the surface expression of both these types of force as displayed on a faulted monocline may be strictly tensional. In the boundary zone between the Colorado Plateaus and the Albuquerque-Belen basin the zone of Basin and Range faulting followed approximately the faulted monocline established in the Laramide orogeny. Therefore the problem of differentiating the structures produced in the two periods of orogeny is not so simple as it is in the Southern Rocky Mountains.

The details of the structural and depositonal history of the Albuquerque-Belen basin during Santa Fe time (late Miocene and Pliocene) may be presented because the vertical subdivision of the Santa Fe formation in the Lower Rio Puerco area introduces the element of time into the late Tertiary geography of central and northwestern New Mexico. The geographic conditions change apace with erosion and deposition. They change abruptly with marked increases in the rate or loci of crustal movements. Whatever the cause, the geographic change is reflected in the local lithology of the basin deposit. The present study of the horizontal and vertical changes of the lithology of the Santa Fe formation has revealed the changing phsyiographic and dynamic development of the Albuquerque-Belen basin and adjacent regions during the late Tertiary. The Quaternary development of these regions is revealed in the pattern of Quaternary erosion surfaces as restored from their remnants.

GEOMORPHOLOGY

INTRODUCTION

The deposition of the Santa Fe formation ceased with the marked deformation at the end of the Tertiary. There followed a long period of stability during which erosion was the dominant process. However, the larger features of the geographic pattern did not change. There persisted along the eastern portion of the Albuquerque-Belen basin the through-flowing master stream, the Rio Grande. Tributary streams graded to the Rio Grande truncated the deformed, unconsolidated beds of the Santa Fe formation in the basin. They stripped the thin edges of the Santa Fe from the uplifted blocks bordering the basins and cut down into the older, more resistant rocks.

The first post-Santa Fe erosion surface, the Ortiz pediment, may be traced for 75 miles west of the Rio Grande onto the gently warped pre-Tertiary rocks of the Colorado Plateaus. Slight contemporaneous and subsequent deformation tilted and locally faulted the Ortiz pediment, and probably caused the formation of a new large tributary by piracy, namely the Rio Puerco. Post-Ortiz erosion cycles were initiated by periodic changes in base level of the Rio Grande. Remnants of two to four partial pediments and terraces were found along the Rio Grande and its major tributaries. Outcrops of resistant basaltic lava interbedded in the Santa Fe formation locally have controlled the drainage pattern, as have extrusions during the Quaternary.

The topography in early post-Santa Fe time was more rugged than the present, for fault-block ranges had just been uplifted around the basin. Erosion during Ortiz time reduced the relief, but post-Ortiz uplift and dissection have produced valleys 500–1000 feet deep in the Ortiz surface. In fact, some of the less resistant rocks of the

original bordering highlands have been reduced to lower levels than the basin deposits themselves, where the latter are protected by resistant caliche or basalt.

CORRELATION OF EROSION SURFACES

Remnants of dissected eroxion surfaces may best be correlated by direct tracing. This method is limited by the extent of preservation of the surfaces. Preservation in turn is determined by the character of the bedrock, the type of cover, and the regime of the dissecting streams.

Remnants of surfaces may also be correlated by comparison of their heights above present stream grades. The height of an old surface is the difference in elevation between the grade of the present stream and the grade of the master stream on the old surface. Ideally, a surface representing one period of stability should have a uniform height along all the major streams of any drainage system. However, this ideal is seldom achieved. The tributaries attain grade at different times in the same period of stability because of variations in rock resistance and in size and regime of the streams. Furthermore, a stream usually works headward as it dissects an old erosion surface, and the lower part of the stream reaches grade before the upper part. Therefore the height of the old surface above the dissecting stream decreases upstream.

Because of these sources of possible error in correlation, the erosional histories of the major streams, namely the Rio Grande, Rio Puerco, and Rio San José, are here considered separately. The oldest and most extensive of the surfaces, the Ortiz, was formed before the modern tributary system was established. This was a surface of relatively low relief and gentle gradients, and its remnants may be correlated over the whole Albuquerque-Belen basin and bordering highlands. All the later surfaces, however, are given local names relating to the particular stream to which they were graded. Correlations from stream to stream are suggested in the legend of the geomorphic map (Pl. 10). Final correlation must await the availability of detailed topographic maps, which, with aerial photographs and reconnaissance field mapping, will permit accurate restoration of old surfaces.

The area covered by the geomorphic map (Pl. 10) was extended on the east edge to the Rio Grande, a maximum of 6½ miles beyond the eastern boundary of the geologic map (Pl. 8). The terraces east of the Rio Grande are not shown.

PRESERVATION OF EROSION SURFACES

General statements.—The old erosion surfaces in the Lower Rio Puerco area are marked and in part preserved by a cover or mantle of one or more of the following types: (1) slightly cemented stream gravel, (2) caliche, (3) wind-laid sand and dust, (4) travertine and travertinous gravel, (5) basaltic lava.

(1) Stream gravel is deposited by the streams which cut the erosion surface. (2) Caliche is developed as a soil zone during the formation of the erosion surface. These two types of cover therefore accurately record the position and form of the erosion surface at the time of its formation, provided there has been no subsequent deformation.

The occurrence of the other three types of cover is controlled in part by processes

unrelated to the formation of the erosion surface. (3) Wind-blown sand and dust may be deposited on an uplifted surface which is being dissected as well as on a surface which is being formed in a given erosion cycle. Thus sand is now being deposited on the Llano de Albuquerque, an uplifted erosion surface. (4) Travertine deposits surround springs, and most springs in the Lower Rio Puerco area are associated with faults. Faults do not necessarily emerge on an erosion surface which is being formed in a given cycle. Travertine therefore may be deposited on an erosion surface which has been uplifted. (5) In a similar way the locus of a volcanic vent has no relation to the form or position of an erosion surface. Lava may thus be extruded on an uplifted surface. The lava from the Cat Hills on the Llano de Albuquerque, for instance was extruded in Recent (?) time onto the Ortiz surface, which had been uplifted in the early Pleistocene. The lava flowed over two breaks in slope onto lower erosion surfaces.

Furthermore, lava, travertine, or wind-blown sand may be deposited on an erosion surface early in the cycle. It then may protect the portion it covers from further erosion during the rest of the cycle. Thus the protected surface and the adjacent unprotected surface may be at different elevations yet represent the same erosion cycle and period of stability.

However, unless there is proof to the contrary, it is assumed (1) that the travertine and lava and wind-blown sand which cover portions of certain erosion surfaces were deposited during the formation of that surface; and (2) that such covers indicate the average position of the surface during the period of stability in which it was formed.

Formation of caliche.—Caliche is best developed on the Llano de Albuquerque, a remnant of the Ortiz erosion surface. It was formerly considered to be a depositional feature, either a great lake deposit of marl (Herrick and Johnson, 1900), or an alluvial fill of the Rio Grande valley (Lee, 1907, p. 20–24; Bryan, 1909). The surface of the Llano is more significantly interpreted, however, as an erosional feature (Bryan and McCann, 1938, p. 4) and the caliche as a soil zone which truncates slightly the deformed sand and gravel beds of the Santa Fe formation. The truncation is apparent in Figure 7, which shows a series of stratigraphic sections taken for a distance of 28 miles along the Ceja. The truncation is also visible at the northwest base of Cerro Los Lunas, a lava cone of Santa Fe age which stood as a residual above the Ortiz surface, permitting the local development of a westward slope to the pediment.

The caliche is the B-horizon of the soil of arid and semi-arid regions, formed by precipitation of the calcium carbonate which is washed through the overlying A-horizon by descending meteoric water, in the manner fully discussed by Price (1933). The layer of pure caliche grades downward into bedrock with nodules and vermicules of caliche. The calcium carbonate precipitated in the B-horizon was derived from two sources: (1) from the A-horizon by leaching by percolating rain water, and, more important, (2) from the calcareous waters of the streams which coursed over the featureless plain and sank into the porous ground. These eroding streams gradually wore down the land surface by removal of the leached A-horizon, and deposited in its place a thin veneer of alluvial sand and gravel. Some of this alluvial material was derived from near-by outcrops of the Santa Fe formation, for it contains pebbles of quartzite, chert, quartz, granite, and volcanics from the pebble layers in the Santa Fe.

The rest of the alluvial material was brought from the plateau country to the west, for it contains slabs and boulders of Cretaceous sandstone and petrified woodmuch larger than any pebbles in the Santa Fe formation. To the alluvial veneer was added some aeolian sand.

As the leached horizon was removed by erosion the top of the caliche layer was in turn leached by the descending waters and calcium carbonate was deposited at the bottom of the layer. The caliche horizon was thus thickened, enriched, and lowered. The thickness and purity of the layer of caliche is determined by the length of the period of uniformity of physiographic conditions, the rate of lowering of the land surface by erosion, the climate, the character of the bedrock, the mineral content of the ground water, and other special factors. The major development of the caliche on the Llano was in the early Pleistocene. When at the end of Ortiz time the Rio Puerco captured the streams which formerly passed eastward, the Llano was deprived of its external supply of calcareous stream waters. Since that time the caliche has probably not thickened appreciably and is now being dissected.

As Woolnough (1928) emphasizes and Price (1933, p. 510) agrees, there may be some thickening and purification of a caliche layer by action of ascending ground water during dry periods, the ascent being induced by capillarity and evaporation. On the Llano de Albuquerque in Ortiz time, however, this process was probably less important than the downward percolation of water, because (1) the caliche layer has a sharp top and a gradational bottom, and (2) the bedrock is porous sand and gravel with openings probably too large for capillary action.

Special features of the caliche on the Llano are discussed in the section on the Llano de Albuquerque.

EXPLANATION OF GEOMORPHIC MAP

To show fully on a map the complex geomorphic relations it was found necessary to devise a rather complex set of symbols and patterns. All the geologic and geomorphic units were first separated into the following categories:

(1) Pre-Quarternary rocks which form residual hills or underlie large areas transitional between erosion surfaces. The resistant Paleozoic and Mesozoic rocks form high mesas and gently sloping hogbacks in the western part of the area, as is indicated by the scarp symbols on the map.

(2) The Quaternary erosion surfaces.

(3) Alluvium and other surficial material on modern and undifferentiated erosion surfaces.

The erosion surfaces themselves were subdivided in three different ways:

(1) With respect to relative age.

(2) With respect to the three major river systems, the Rio Grande, Rio Puerco, and Rio San José. Two to four erosion surfaces were distinguished along each of these rivers and were designated by different letter symbols; correlation is indicated by coloring.

(3) With respect to the covers, which were so important in the preservation and identification of the erosion surfaces. A different pattern and a different symbol suffix is used to distinguish the four types of cover; travertine (circle pattern, suffix

tr), basalt (grid pattern, suffix b), wind-blown sand (dot pattern, suffix s), and gravel or caliche (no pattern or symbol suffix). Thus on the Llano de Albuquerque the Ortiz surface (shown by a purple color and the general symbol Qo) is covered on the north with caliche (Qo), in the center with basalt (Qob), and in the center and south with wind-blown sand (Qos). At the same time it can be seen at a glance that the basalt from the Cat Hills (grid pattern) in the center of the Llano flowed from the Ortiz surface (Qob) down onto the Cochiti surface (Qcb) and then onto the Sequando Alto (Qsab). Similarly in the west the basalt from Cerro Verde (grid pattern) flowed northward over the Mush Mesa surface (Qmmb) and then down onto the Suwanee surface (Qsub).

ORTIZ SURFACE AND ITS REMNANTS

General statements.—The Ortiz surface was named by Bryan (1938, p. 215) from the conical plain (Ogilvie, 1905) which surrounds the Ortiz Mountains on the east side of the Santo Domingo Valley. Bryan traced this surface southwestward into the Albuquerque-Belen basin, where it is the first surface cut on the deformed unconsolidated beds of the Santa Fe formation. It extends beyond the limits of the structural basin, however, and onto the pre-Tertiary rocks of the bordering highlands. It was formed in the early Pleistocene when the Rio Grande, the local base level, flowed 400 to 500 feet above its present elevation.

Bryan and McCann (1938, p. 9) prepared a map showing the drainage pattern of central New Mexico for Ortiz time. This map has been enlarged and elaborated by the writer on the basis of field work in the Lower Rio Puerco area and study of topographic maps and aerial photographs not used by Bryan and McCann. The map (Fig. 12) shows the western portion of the Albuquerque-Belen basin and that part of the plateau country to the west which was drained by the tributaries of the Rio Grande. The boundaries of certain geologic formations are shown to illustrate the relation of rock resistance to stream pattern. The Ortiz surface as contoured is tilted. Four faults with late Ortiz or post-Ortiz movement are shown on the Llano de Albuquerque, and one west of Mount Taylor.

On the east side of the asymmetric Rio Grande valley the Ortiz surface is probably represented only by narrow benches cut on pre-Tertiary rocks at the west base of the Manzano Mountains. Elsewhere on the east side it has been removed by the short active streams heading in the high ranges on the east (Bryan and McCann, 1938, p. 12).

On the west side of the Rio Grande the Ortiz surface is more extensively preserved. Within the limits of the structural depression the largest remnant is the Llano de Albuquerque, the long caliche-capped mesa between the Rio Puerco and the Rio Grande. Another probable remnant is the northern portion of Sabinas Solas, southeast of Lucero Mesa. In the plateau country west of the basin the Ortiz surface is represented by large mesas capped by basalt and, in a few cases, by travertine.

The basalt on Gallina and Pato Mesas, southwest of Lucero Mesa, is probably of early or middle Santa Fe age. These mesas stand about 1000 feet above the restored Ortiz surface as represented by Lucero Mesa and Mesa del Oro. Farther west some of the remnants here interpreted as Ortiz may actually be older. These regions had

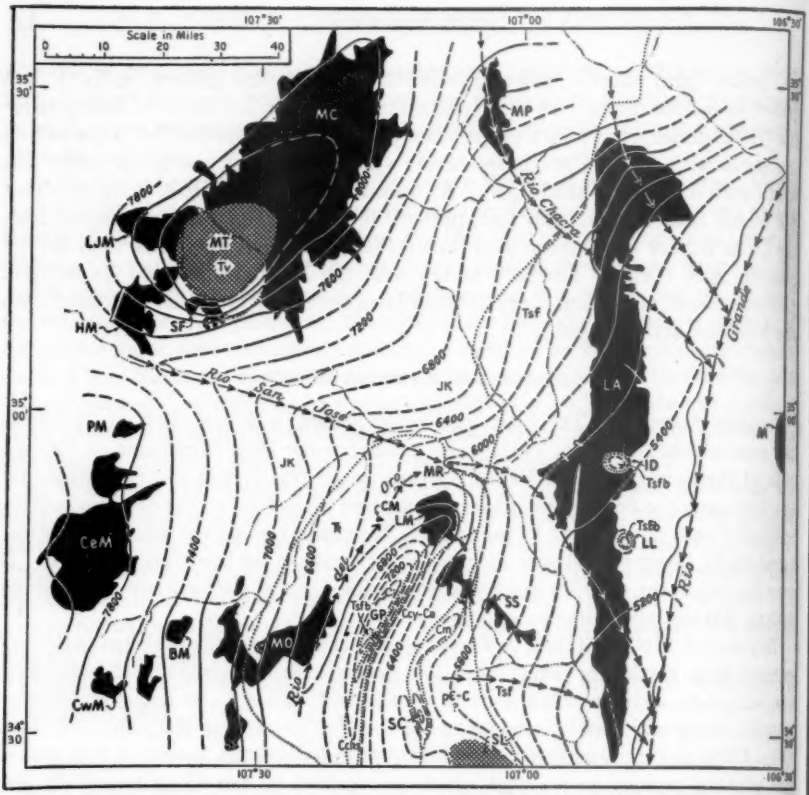


FIGURE 12.—*Paleogeographic map of west-central New Mexico for early Pleistocene*

Contours restored on Ortiz erosion surface. Contour interval 200 feet. Principal modern streams shown for location.

Tsf —Santa Fe formation: slightly cemented sand, silt, and gravel; non-resistant.
Tsfb—Basalt flows in Santa Fe formation: resistant.
Tv —Mid-Tertiary non basaltic volcanics.
J-K —Jurassic and Cretaceous sandstone and shale: resistant.
TR —Triassic shale and sandstone: non-resistant.
Cchs—Hondo and San Andres limestone members of Chupadera formation: resistant.
Ccy —Yeso member of Chupadera: non-resistant sand and gypsum.
Ca —Abo red beds: mostly non-resistant.
Cm —Magdalena limestone: resistant.
pC —Pre-Cambrian complex: resistant.
Solid black pattern—remnants of Ortiz surface.
Grid pattern—uncontoured residuals above Ortiz surface.
Dotted line—stratigraphic and fault contacts of formations.
Heavy white line on LA and HM—Ortiz or post-Ortiz fault.
Lines of short arrows—major Ortiz streams.

BM	Broom Mountain Mesa	M	Bench at base of Manzano Mountains
CM	Carlos Mesa	MC	Mesa Chivato
CeM	Cebolleta Mesa	MO	Mesa del Oro
CwM	Cachow Mesa	MP	Mesa Prieta
HM	Horace Mesa	MR	Mesa Rosario
ID	Isleta lava dome	MT	Mount Taylor
La	Llano de Albuquerque	PM	Putney Mesa
LJM	La Jara Mesa	SC	Sarco-Cimarron Mesa
LL	Cerro Los Lunas	SF	San Fidel Mesa
LM	Lucero Mesa	SL	Sierra Ladron
		SS	Sabinas Solas

been undergoing erosion since the early Tertiary. Some of the basalt flows in the Mount Taylor area are of Pliocene age (Hunt, 1938, p. 57). Most, however, are probably Pleistocene and were extruded on the western portions of the Ortiz surface.

The restored contour map for Ortiz time (Fig. 12) may be compared with the paleogeographic maps for Santa Fe time (Figs. 4, 5). In early and middle Santa Fe time streams flowed from the Zuñi and Mount Taylor regions directly across the Lucero anticline into the Gabaldon playa in the basin. In late Santa Fe time renewed uplift of the Lucero anticline caused the playa to be drained eastward to the ancestral Rio Grande. Consequent streams flowed eastward and probably westward off the uplifted anticline.

This pattern persisted throughout Ortiz time and resulted in three large residual areas. (1) The Mount Taylor volcanic center on the northwest portion of the map had been present since the middle Tertiary. (2) Sierra Ladron on the south had been an actively rising highland since the middle Tertiary (Denny, 1940a, p. 105). It is made of pre-Cambrian crystalline rock and Carboniferous limestone. (3) Sierra Lucero was uplifted in late Santa Fe time. By Ortiz time it consisted of two main ridges, as now. The western ridge, about 1000 feet high, was held up by the resistant caps of Pliocene (?) basalt of Pato and Gallina mesas, and by the resistant sandstone and limestone beds of the Hondo and San Andres members of the Chupadera formation. The eastern ridge, 200 to 600 feet high, was formed of Magdalena limestone. The broad valley between the two ridges was underlain by the red beds of the Abo formation and the soft sand and gypsum of the Yeso member of the Chupadera formation.

West of Sierra Lucero was a lowland underlain by Triassic rocks. The rest of the plateau country shown on the map was underlain by flat-lying Cretaceous and Jurassic rocks. These probably produced a topography similar to the present—a series of strip surfaces on resistant layers of sandstone separated by gentle breaks in slope. There was probably a noticeable scarp around the edge of outcrop of the Cretaceous and Jurassic rocks, leading down to lowlands developed on Triassic rocks. Such a a scarp is preserved under the lava of Mesa del Oro. It is also apparent between Mesa Rosario, which is an Ortiz remnant, and Mesa Gigante (to the north) which is high enough to be an Ortiz remnant. The fault boundary between the Cretaceous rocks and the Santa Fe formation in the northwestern part of the basin had little effect on the topography. The Ortiz surface cut evenly across the slightly cemented alluvial beds of the Santa Fe formation and the interbedded sandstone and shale of the Mancos and Mesaverde formations.

In Ortiz time there was no lower Rio Puerco. There were four major western tributaries to the Rio Grande of the Albuquerque-Belen basin: (1) A short stream headed in the Sierra de los Valles and flowed south-southeastward to enter the Rio Grande above Albuquerque. This drainage has since been captured by the Rio Jemez. (2) The hypothetical Rio Chacra (Bryan and McCann, 1938, p. 9) headed in the Sierra Nacimiento and the San Juan Basin and flowed along Mesa Prieta and thence obliquely across the Llano de Albuquerque. It probably entered the Rio Grande near Albuquerque rather than near Los Lunas, as suggested by Bryan and McCann. Such a course is indicated both by the form of the contours on the Llano

and by the presence of two hills of basaltic lava west of Los Lunas, namely, the Isleta lava dome and Cerro Los Lunas. (3) The ancestral Rio San José probably headed in the saddle between Mount Taylor and the Cebolleta Mesa region. In the Lower Rio Puerco area it received a large tributary from the south, the hypothetical Rio del Oro, which drained the lowland of Triassic rocks west of Sierra Lucero. The Rio San José then flowed southeastward obliquely across the Llano de Albuquerque

TABLE 3.—*Gradients of Ortiz and modern rivers*

ORTIZ RIVERS	Gradient in feet per mile	Length of river in miles
Ancestral Rio Grande	8	65
Rio Chacra	50	40
Ancestral Rio San José (on plateaus)	42	38
Ancestral Rio San José (entire)	35	60
MODERN RIVERS		
Rio Grande	4	60
Lower Rio Puerco	13	100
Rio San José	25	55

and entered the Rio Grande near Belen. (4) A short tributary headed in the Sierra Lucero and entered the Rio Grande near Abeytas.

Table 3 shows the gradients of some of the Ortiz rivers and their present counterparts. The gentler gradient on the portion of the ancestral Rio San José within the Albuquerque-Belen basin is probably a result of difference in rock resistance. The Lower Rio Puerco originated by capture of the ancestral Rio San José and the Rio Chacra. Most of its course is within the unconsolidated beds of the Santa Fe formation.

However, Table 3 shows that the average gradient of the Ortiz rivers was steeper than the average gradient of their successors. The differences in gradients are readily seen by a comparison of elevations of the Ortiz surface at various points along corresponding rivers. The best control for the Ortiz surface is perhaps along the ancestral Rio San José. At its entrance to the Rio Grande it was about 400 feet above the present Rio San José at Mesa Rosario about 600 feet, and south of Mount Taylor about 1000 feet. Similarly, the Ortiz Rio Grande was about 400 feet above the modern river at the southern end of the map area, and 500 feet at the northern end near the type locality of the Ortiz surface.

One would expect the average gradients of the Ortiz rivers to be gentler than the average gradients of the modern streams because the topography of Ortiz time had less relief than the modern topography. The reverse relation, however, is true. This condition is probably accounted for by a southeastward tilting of the Oritz surface, *i.e.* a renewed subsidence of the Rio Grande depression. Such a tilting would initiate the dissection of the surface as the streams sought to flatten their steepened gradients. The region of maximum subsidence may have been far south of the Albuquerque-Belen basin and may have been a locus of deposition. However, the effect upstream was the dissection of the Ortiz surface.

Independent evidence for late Ortiz and post-Ortiz deformation are the faults which displace the caliche capping on the Ortiz surface.

Llano de Albuquerque.—The Llano de Albuquerque is a long narrow mesa which separates the Rio Puerco from the Rio Grande. It is about 70 miles long and is widest (12 miles) at its northern end. The total area representing the Ortiz surface is about 260 square miles. The surface slopes southeastward from 6750 feet above sea level at the northern end to about 5100 feet at the southern tip. The prominent west-facing scarp at the west edge of the mesa (Pl. 3, fig. 2) is 500 feet high at the northern end but averages 150 to 250 feet for the rest of the distance. A fringe of cliff dunes at the west edge of the Llano gives the scarp the name Ceja (Eyebrow) del Rio Puerco. Except for a 10 mile stretch east of the junction of the Rio San José and the Rio Puerco, the scarp is being actively pushed back and kept sharp and straight by innumerable small streams which fan out distally on the old flood plain of the Rio Puerco valley.

The scarp which limits the Llano on the east, the Cejita Blanca, is less conspicuous than the Ceja, except south of Cerro Los Lunas.

The Llano is a smooth grass- and shrub-covered plain now drained southeastward by a few long, shallow valleys (Bryan and McCann, 1938, p. 7). The runoff is slight because of the porous nature of the bedrock and locally because of the cover of wind-blown sand. The Llano has resisted complete dissection largely because of a capping of caliche, well-exposed as a white rim along the whole length of the Ceja and part of the Cejita. The formation of the caliche is described in detail in the section on Preservation of Erosion Surfaces.

The average thickness of the caliche cover on the Llano is about 10 feet. However, at the northern edge of the Lower Rio Puerco area (Pl. 8, locality 1) the caliche has a local thickness of 150 feet. This abnormal section is on the east or downthrown block of the eastern of the two major faults in the Sand Hill fault zone (Pl. 3, figs. 2, 3). On the west side of this fault is the Upper Buff member of the Santa Fe formation. The uppermost 10–15 feet of caliche covers both blocks and the fault as well. The complete section of calichified sand and gravel is presented in Table 4.

In this section there are 11 distinct horizons of calichified sand and gravel, with an average thickness of 2 feet. They are separated by horizons which contain only nodules and vermicules as concretions of caliche. Rough chemical tests indicate that the sand in the caliche horizons contains about 11 per cent $CaCO_3$, and the sand in the leached horizons between contains only 3 per cent $CaCO_3$. The thick caliche cap which overlies the whole section and the fault as well contains 36 per cent $CaCO_3$.

This thick section of caliche may have originated in the manner set forth in the series of diagrams in Figure 11, which has been discussed in part in the section on structure. The post-Santa Fe pre-Ortiz movements on the boundary faults of the Albuquerque-Belen basin amounted to several hundred feet, and it seems logical that a fault scarp and an adjacent depression could be formed, permitting the local accumulation of at least 150 feet of sand and gravel. If this depression subsided only a few feet at a time, then a horizon of caliche could be developed by soil-forming processes during each time of quiescence. With the next small subsidence the caliche

TABLE 4.—*Section on east block of east fault of Sand Hill fault zone*

Feet	
20	Cliff dunes
2	Soil—gray, sandy
3	Sand—buff
2	Caliche—weakly developed
5	Sand—buff, with pebbles of quartzite, chert, granite, and nodules and vermicules of caliche
3	Caliche—strongly developed
3	Sand and gravel—with caliche nodules
3	Sand—buff, pebbly
4	Caliche—strongly developed, sandy and gravelly
3	Pebbly sand—with nodules and vermicules of caliche
2	Caliche
2	Sand—buff, with vermicules of caliche
7	Caliche—strongly developed, horizontal and vertical jointing
4	Sandy gravel—pebbles of quartzite, granite, chert, andesite, and quartz
3	Caliche
6	Sand—buff, with vermicules of caliche
1	Caliche—weakly developed
9	Sand—buff
2	Caliche—weak
6	Sand
3	Caliche—strong
10	Sand—buff, with vermicules on top
3	Caliche—weak
2	Sand
4	Caliche
5	Sand
3	Caliche
3	Sand
1	Caliche
3	Sand
2	Caliche
3	Sand
2	Caliche
4	Sand
2	Caliche
7	Sand
2	Caliche
5	Sand—buff, with horizons of vermicules and nodules of caliche
4	Caliche
3	Sand
3	Caliche
6	Sand
60	Gravel and sand—nodules of caliche at certain horizons; pebbles of granite, quartzite, chert, andesite, and quartz, in that order of abundance. The Upper Buff member of the Santa Fe formation.

layer and overlying leached layer would be buried by more sand and gravel brought into the depression by streams and wind, and this layer in turn would be calichified.

This thick section of caliche may be traced for 1½ miles along the Ceja. It has

been completely removed from the block west of the fault and disappears to the east, north, and south under the Llano. The next exposure east of the fault is 2½ miles east of the Ceja, and there is no indication there that the caliche is more than the usual 10 feet thick. Therefore this thick accumulation of caliche was probably local.

Similar though less pronounced local thickening of caliche was noted in two localities (12 and 19 on Pl. 8) on the Isleta Reservation, 20 and 22 miles respectively south of locality 1 just described. In both instances the lower 10 feet of a 20-foot section of calichified sand and gravel is faulted against uncalichified gravel of the Santa Fe formation. The southern of these two faults has experienced two periods of movement, as in the Sand Hill fault zone, for a distinctive tan sand horizon is completely faulted out from the middle of the section (Fig. 7).

These three faults on the western edge of the Llano are shown on the map of the restored Ortiz surface (Fig. 12), for they were active in late Oritz time, after the climax of post-Santa Fe movements.

More significant in the question of late deformation, however, is the discovery by Denny (1941) at the southern end of the Llano de Albuquerque of a fault which displaces even the top 10-foot layer of caliche, and which is therefore of post-Oritz age. The fault produced a small westward-facing scarp which may be traced on the aerial photographs for 6 miles. Although the movement on this fault amounts to only a few tens of feet, here is definite evidence for post-Ortiz deformation, a conclusion which is independently indicated by the steepness of the gradients on the restored Oritz surface. Indeed such late Quarternary movements in the Rio Grande depression are not surprising, for the region had been subsiding since the middle Tertiary. Recent fault scarps along the bases of the Magdalena and Bear mountains (Denny, 1940a) and historic earthquakes in the Socorro region indicate still later movements.

The Llano de Albuquerque is covered at two localities by probably Recent basaltic volcanoes and lava flows. The lava from the five Albuquerque volcanoes (Pl. 3, fig. 2) was erupted on the east side of the Llano northwest of Albuquerque. It flowed eastward over the Cejita Blanca onto the next lower erosion surface; thus, it was erupted after the dissection of the Ortiz surface had begun. On the Isleta Reservation in the central portion of the Llano there are cinder cones and lava flows of an even fresher aspect. There are 16 distinct cinder cones, the Cat Hills, along a line which trends slightly east of north for about 5 miles. The largest cone is about 1000 feet in diameter and has a broad crater at the top about 5 feet deep. The lava was probably erupted along fissures and has retained such primary features as pressure ridges and collapsed lava tubes. It extended for at least 8 miles eastward, flowing over the Cejita Blanca onto the next surface below and then over another break in slope onto a still lower surface, reaching to within 2 miles of the Rio Grande. It also flowed southward down a broad post–Ortiz valley in the western portion of the Llano.

Besides the lava covering at these two localities, the Llano is locally covered by wind-blown sand. (*See* section on wind-blown sand.)

Northern part of Sabinas Solas.—Sabinas Solas is the extensive grassy plain between Gabaldon Badlands and Sierra Ladron in the southern portion of the Lower Rio Puerco area. It covers about 125 square miles and is drained eastward by intermittent streams which flow in part through broad, steep-walled cañadas, in part across

extensive alluvial swales. Sabinas Solas is a composite erosion surface representing at least three stages. The surface cuts indiscriminately across the soft Santa Fe formation and the resistant Carboniferous and pre-Cambrian rocks.

The northern part of Sabinas Solas is separated from the Gabaldon Badlands by a northeastward-facing scarp held up by a capping of calichified pediment gravel 5 to 10 feet thick, which cuts unconformably across the tilted Santa Fe formation. This northern portion of Sabinas Solas, about 6 square miles in area, is believed to be a small remnant of the Ortiz pediment. Its projected southeastward slope reaches a point about 400 feet above the present elevation of the Rio Grande. The Llano de Albuquerque in this latitude is 370 to 400 feet above the Rio Grande (Denny, 1941, p. 236).

Lucero Mesa.—A third large remnant of the Ortiz surface in the Lower Rio Puerco area is Lucero Mesa, located southwest of the junction of the Rio San José and the Rio Puerco. It is a basalt-capped mesa of irregular shape, actually divided into two sections by steep tributaries of the Rio Puerco. The total area covered by the basalt is about 21 square miles. The highest portion of the mesa is near the center (*ca.* 6800 feet). This part was apparently the location both of a drainage divide of the Ortiz surface (*see* Figure 12) and the center of eruption of the lava. The mesa decreases in elevation in all directions from this central portion and at the southern end is only about 5950 feet above sea level.

The mesa is bordered on all sides by scarps which range in height from 20 feet on the west edge to 300 feet on the east-central portion. The height and steepness of the scarp are controlled by two factors: (1) the character of the rock underlying the capping, and (2) the vigor of the streams which head in the scarp. The capping of the northern half of the mesa is underlain by soft Triassic shale and sandstone, which have permitted extensive landsliding (Pl. 5; Pl. 6, fig. 1). On the southern half of Lucero Mesa the basalt is underlain by the interbedded sandstone, limestone, and gypsum of the Permian formations, rock types which are not so conductive to landsliding. The scarps are steep and bare and show narrow slide cones of basalt boulders (Pl. 1, fig. 1).

In general the scarps are steeper and cleaner on the east flank, where the steep gullies at the heads of Arroyo Carrizo and Arroyo García have cut back westward through the hogbacks east of Lucero Mesa and have dissected broad upland valleys at the base of Lucero Mesa (Pl. 1, fig. 1). Arroyo Carrizo has cut right through the mesa itself and has captured the headwaters of the longer and gentler Arroyo Comanche. Elsewhere on the west flank of Lucero Mesa the scarp is generally less steep. At the very southern end of the mesa a hogback of Magdalena limestone, the northward continuation of Cimarron Mesa, projects through the basalt cap.

Underlying the basalt in the central portion of Lucero Mesa is a deposit of travertine and travertinous gravel which outcrops along a break in slope across the center of the mesa and on the scarp at the east and west edges. Figure 1 of Plate 1, shows how the travertine rests in a broad channel cut in the Chupadera formation. The travertine was deposited on the Ortiz erosion surface as a broad dome or terrace. The basalt, which was apparently erupted from fissures near the center of the travertine deposit, flowed out on top of the travertine and down onto the surrounding surface.

Subsequent erosion has removed the basalt from the break in slope of the edge of the dome, thereby exposing the travertine.

Travertine caps a number of small buttes west of Lucero Mesa and forms the northern end of Mesa del Oro. These are all believed to be remnants of the Ortiz surface. One of then, Carlos Mesa (Pl. 4, fig. 2), has also a capping of basalt. The easterly slope of this small remmant serves to limit the position of the hypothetical Rio del Oro.

Mesa Rosario.—North of Lucero Mesa and just south of the railroad station of Suwanee is a distinctive basalt-capped butte known as Mesa Rosario or Mesa Redonda. The basal diameter is about a mile; the basalt cap, although almost a mile long, is only a few hundred feet broad. The basalt is underlain by Cretaceous and Jurassic rocks which have the structure of a syncline with a fault along the axis.

The basalt capping is separated from the underlying tilted Cretaceous rocks by about 10 feet of calichified gravel formed during the development of the Oritz pediment. The elevation of the caliche here is about 6000 feet. Mesa Gigante, a strip surface on Cretaceous sandstones, is only 5 miles to the north and is 6600 feet above sea level. It was certainly no lower in Ortiz time. The steep slope thus indicated between Mesa Gigante and Mesa Rosario was a reduced fault-line scarp.

Mesa del Oro.—One of the largest remnants of the Ortiz surface is Mesa del Oro, which covers a total area of about 85 square miles. The erosion surface under the basalt cap slopes in general eastward from 7300 feet to 6400 feet above sea level. Just west of the border of the Lower Rio Puerco area the basalt flowed eastward over a scarp formed by Cretaceous sandstone onto Triassic rocks, and the whole eastern portion of the mesa is underlain by soft Triassic shale and sandstone. Landsliding of basalt blocks on the soft shale is particularly conspicuous along the northwestern scarp of this portion.

The northern end of Mesa del Oro is capped by a maximum thickness of 150 feet of travertine and travertinous gravel with or without the additional cover of basalt.

Cebolleta Mesa region.—The outline and contours on Cebolleta Mesa are taken from an unpublished map made available to the writer by Doak C. Cox. The total area of this lava-capped remnant of the Ortiz surface is about 110 square miles.

Darton's reconnaissance geologic map (1928, Pl. 26) shows three smaller basalt-capped mesas southeast of Cebolleta Mesa. These are Cachow Mesa, Broom Mountain Mesa, and an unnamed mesa between the two. The total area of these three probable Ortiz remnants is about 20 square miles.

Mount Taylor region.—The pile of nonbasaltic volcanics which is Mount Taylor was formed in the Miocene (?) (Hunt, 1938). During Pliocene and early Pleistocene it remained as a residual above the pediment which was cut around it. This pediment has been preserved in part by basaltic lava flows which emerged from vents at the base of the mountain and in the area to the northeast (Johnson, 1907). Some of the basalt was probably extruded in the Pliocene before the completion of the Ortiz pediment proper, thereby protecting portions from further lowering. So the restored Ortiz surface for this region may be composite, representing positions of the land surface in both Pliocene and early Pleistocene.

The total area covered by the basalt of Chivato, Prieta, San Fidel, Horace, and La Jara Mesas is over 400 square miles.

Post-basalt, and therefore presumably post-Ortiz, faulting occurred on the southwest edge of Horace Mesa (Hunt, 1938, p. 75). The basalt was dropped 150 feet on the west.

ORIGIN OF THE RIO PUERCO

During Ortiz time the lower Rio Puerco was non-existent. The upper Rio Puerco, as the hypothetical Rio Chacra, may have had approximately its modern course as far south as Mesa Prieta. Thence the old Rio Chacra flowed southeastward across the Llano de Albuquerque to enter the Rio Grande near Albuquerque, whereas the modern Rio Puerco flows south to enter the Rio Grande near Bernardo, 50 miles south of Albuquerque. The southern portion of the Lower Rio Puerco area, which now drains to the Rio Puerco, drained in Ortiz time to the ancestral Rio San José, which flowed eastward across the Llano to the Rio Grande near Belen.

Ortiz time closed with the piracy of these two old eastward-flowing streams by the lower Rio Puerco, which worked headward generally along the western limits of the soft Santa Fe formation (Bryan and McCann, 1938, p. 12–14). Denny (1940b, p. 239–242) suggests that this capturing stream may have started in a graben located west of and parallel to the small north-south post-Ortiz fault at the southern end of the Llano de Albuquerque. This explanation is purely hypothetical, but post-Oritz deformation strong enough to initiate such stream piracy is independently indicated by the evidence of the southward tilting of the whole Ortiz surface. Furthermore, the post-Ortiz cinder cones of the Cat Hills on the Isleta Reservation mark a zone of weakness which is in direct line with the lower 20 miles of the Rio Puerco, whose position may thus also be determined by some structural weakness.

POST-ORTIZ EROSION SURFACES

General statement.—The long period of essential stability in the early Pleistocene during the formation of the Ortiz pediment was terminated by a change in base level of the Rio Grande in central New Mexico, probably a result of renewed subsidence of the Rio Grande depression. As a result, the Rio Grande and its tributaries commenced to dissect the extensive Ortiz surface, and the lower Rio Puerco originated by capture of the upper portions of the ancestral Rio San José and Rio Chacra. The partial pediments and terraces formed in the following periods of stability are graded to the Rio Puerco and the Rio San José as well as to the Rio Grande.

As explained in the section Correlation of Erosion Surfaces, the post-Ortiz surfaces along each of these three major streams of the Lower Rio Puerco area will be described separately. Bryan (1932), Bryan and McCann (1936), Bryan and Upson (unpublished), Denny (1941), and Nichols (1933) have studied the terraces north, south, and west of the Lower Rio Puerco area, which is therefore strategically located for correlation of Quaternary physiographic events in west-central New Mexico. In addition to the major terraces described, there are unmapped patches of still lower terraces. Furthermore, most of the modern streams are cutting arroyos on an average of 5–10

feet deep in their most recent flood plains. The arroyo of the Rio Puerco, however, is over 40 feet deep at the northern end of the area. The depths of the modern arroyos were not included in the figures for the heights of the older terraces.

Along the Rio Grande.—The partial pediments and terraces along the Rio Grande in the Albuquerque-Belen basin may best be studied on the new topographic map of the Albuquerque quadrangle, the western part of which is included on Plate 10.

On this map the following surfaces may be identified (figures indicate heights above present stream grades): Ortiz, 500 feet; La Bajada, 300 feet; Cochiti, 200 feet; Segundo Alto, 125 feet; Llano de Sandia, 50–75 feet.

The La Bajada surface (outside the area covered by Plate 10) was first described from the Santo Domingo Valley (Bryan, 1938, p. 217; Bryan and Upson). In the Albuquerque-Belen basin it is represented by the extensive plain at the west base of the Manzano Mountains, southeast of Albuquerque. The Albuquerque Airport is located on the northern end of this remnant. The surface near the airport is essentially flat and may mark the position of the Rio Grande in La Bajada time (middle Pleistocene). The La Bajada surface here is marked by a thick cover of caliche which caps a steep, 300-foot scarp facing the Rio Grande, Tijeras Arroyo, and other streams which dissect it.

Southward the La Bajada surface may be correlated with the Tio Bartolo surface at the west base of the Los Pinos Mountains (Denny, 1941, p. 236) and in the Socorro area (Bryan, 1932).

The Cochiti surface also has its type locality in the Santo Domingo valley (Bryan and Upson), where it is 175 feet above the present Rio Grande. It was formerly called the Peña Blanca surface (Bryan, 1938, p. 217). On the east side of the Albuquerque-Belen basin it is well developed at the north base of the Sandia Mountains (Stearns, personal communication). On the west side of the Rio Grande it may be traced from Jemez Creek southward as an irregular dissected surface about 200 feet above the present Rio Grande. Northwest of Albuquerque it is protected by flows of basaltic lava. The lava flowed from the Albuquerque volcanoes out onto the Ortiz surface, thence over the scarp onto the Cochiti surface. The Cochiti surface cannot be traced directly south of the Albuquerque volcanoes, but a small remmant of it may exist east of the Cat Hills. In the San Acacia area the Valle de Parida surface (Denny, 1941, p. 242), 150 feet above the Rio Grande, may be correlated either with the Cochiti (Bryan, 1938, p. 217) or with the Segundo Alto.

The next surface below the Cochiti surface in the central portion of the Albuquerque-Belen basin is the Segundo Alto, best developed due west of Albuquerque as a broad terrace about 125 feet above the present Rio Grande. From the Albuquerque volcanoes southward on the west side of the river it is the broadest of the post-Ortiz terraces. West of Isleta it is locally covered with basaltic lava from the Cat Hills which flowed out onto the Ortiz surface, then over a scrap onto the Cochiti surface, and finally over another break in slope onto the Segundo Alto. In the San Acacia area the Segundo Alto may be represented either by the Valle de Parida surface, 150 feet above the Rio Grande, or a fill terrace at 100 feet.

The Llano de Sandia surface is a broad plain shown on the Albuquerque sheet at the west base of the Sandia Mountains. It has average gradient of about 18 feet per

mile over a breadth of 4 to 9 miles from the abrupt mountain slope to the 60- to 75-foot scarp which separates it from the Rio Grande flood plain. North of the Sandia Mountains the Llano de Sandia surface gives way to the higher Cochiti surface. Southward it is replaced by a more gently sloping surface which is University Heights in Albuquerque. Bryan (1909) has shown that this latter surface, which is about 200

TABLE 5.—*Correlation of terraces along the Rio Grande.*

Symbols are those used on Plate 10. Figures indicate height (in feet) of grades above the present Rio Grande.

Santo Domingo Valley		Albuquerque-Belen Valley			San Acacia Area	
Ortiz	500	Qo	Ortiz	500	Ortiz	400
La Bajada	250		La Bajada	300	Tio Bartolo	250
Cochiti	175	Qc	Cochiti	200		
					Valle de Parida	150
		Qsa	Segundo Alto	125		
					Cut and fill	100
Rio Grande	60–70	Qlds	Llano de Sandia	50–75	Cañada Mariana	50–75
Sile	25					

feet above the Rio Grande flood plain, is a depositional surface. It is underlain by alluvial-fan material deposited by the old Rio Tijers on the southern end of the Llano de Santa Surface. Southward this depositional surface rises to the La Bajada erosional surface on which the Albuquerque Airport is built.

The Llano de Sandia surface, 50 to 75 fet above the present Rio Grande, may be correlated with the 60- to 70-foot fill terrace in the Santo Domingo Valley named by Bryan and Upson the Rio Grande terrace. West of Albuquerque, just south of U. S. Highway 66, is a narrow terrace called the Primo Alto about 75 feet below the Segundo Alto and thus 50 feet above the Rio Grande flood plain. This terrace may be traced for 5 miles southward to Hubbell Lake and may be correlated with the Llano de Sandia surface, which is so well developed on the east side of the valley. In the San Acacia area the Llano de Sandia surface may be correlated with the Cañada Mariana surface, which is 50 to 75 feet above the Rio Grande.

Table 5 summarizes the probable correlation of the surfaces of the Rio Grande in the central portion of the Albuquerque-Belen Valley with those in the Santo Domingo Valley to the north (Bryan, 1938, p. 217; Bryan and Upson), and with those of the San Acacia area to the south (Denny, 1941).

Along the Rio Puerco.—In the San Acacia area near the junction of the Rio Puerco and the Rio Grande Denny (1941) described the following post-Ortiz erosion surfaces (figures indicate heights above present stream grades): Tio Bartolo, 250 feet; Valle de Parida, 150 feet; Cañada Mariana, 50–75 feet.

The Tio Bartolo surface may be identified in the Rio Puerco drainage at the north base of Sierra Ladron (Denny, 1941, p. 228). It cannot be located definitely any farther north, however, and therefore does not appear on Plate 10.

The Valle de Parida surface forms the western border of Sabinas Solas. At the bases of Sarco and Cimarron Mesas it is covered by travertine at least 100 feet thick. The travertine was deposited by springs associated with the Lucero fault zone. The

eastern portion of Sabinas Solas is probably also a remnant of the Valle de Parida surface. A rough profile taken in T.5. N., R.1. W. indicates that this portion was formed when the Rio Puerco flowed about 175 feet above its present elevation. The Valle de Parida surface is separated from the small remnant of the Ortiz surface on the northern border of Sabinas Solas by a gentle break in slope.

The Cañada Mariana surface appears on the eastern part of Sabinas Solas (*e.g.* near Huning's Ranch) as a narrow bench below the Valle de Parida surface along the major cañadas. Upstream, however, the bench broadens and apparently forms most of the central part of Sabinas Solas. Correlation of the surfaces on Sabinas Solas by both Denny and the writer was largely by study of aerial photographs and by reconnaissance field work. More detailed mapping and better topographic control might change the correlations.

The major streams which drain Sabinas Solas have cut back through Sarco, Cimarron, and Lucero Mesas and have formed a broad alluviated valley, called Los Valles, between these mesas and the long ridge on the west topped by Pato and Gallina Mesas. The local base level of erosion of Los Valles is the resistant sill of travertine formed in the outlets by springs along the Lucero fault zone. The drainage of the northern part of Los Valles is being captured by the tributaries of Arroyo Carrizo, which cuts directly through Lucero Mesa and has a much shorter course to the Rio Puerco than has the Arroyo Comanche.

Sabinas Solas ends abruptly on the north in a scarp which faces the Gabaldon Badlands. The scarp, which is capped by the caliche of the Ortiz surface, retreats rapidly due to the vigor of the short Arroyo Alamo and Arroyo Carrizo. These two tributaries of the Rio Puerco have long been separated from the streams which formed Sabinas Solas, and have formed their own erosion surfaces. Many of the ridges in the Gabaldon Badlands are capped with a gravel cover 75 to 150 feet above the tributaries of the Arroyo Alamo. These are probably part of the Valle de Parida surface.

East of the hogbacks of the Lucero fault zone are terraces capped by cemented gravel or travertine. Just north of Arroyo Carrizo is a small butte 400 feet high capped by 30 feet of cemented gravel resting on tilted Santa Fe. The hogbacks just to the west are made of steeply dipping beds of Chupadera sandstone and limestone, but they have remarkably flat tops (Pl. 9). The butte and these hogbacks are remnants of an old erosion surface, probably the Ortiz surface. The lower terraces east of the hogbacks are gravel-covered erosion remnants which are cut either over the Santa Fe formation or on the older rocks. Some are fill terraces, capped by layers of cemented gravel. On the geomorphic map the two principal terraces are tentatively correlated with the Valle de Parida and Cañada Mariana surfaces. There are small remnants of a lower, 30-foot terrace along the Arroyo Carrizo, but these were not mapped.

On the east side of the Rio Puerco valley north of the entrance of the Rio San José there are many long spurs extending from the base of the scarp of the Ceja westward to the center of the valley. The spurs are remarkably straight and continuous for as long as 3 miles. They are only a few hundred feet broad at the base. The flattish or rounded tops bear a cover of gravel and locally of wind-blown sand. The spurs are remnants of an erosion surface graded to the Rio Puerco when the latter flowed about

60 feet above the present valley flat (100 feet above the Rio Puerco arroyo bottom). This surface may be correlated with the Cañada Mariana surface to the south. It also may the correlated with the Rito Leche surface of the upper Rio Puerco valley 50 miles to the north (Bryan and McCann, 1936). The Rito Leche surface in the type locality is 75 to 85 feet above the present stream grades and is cut in part on resistant beds of Cretaceous and Eocene sandstone. The Cañada Mariana surface in the type region is cut on the unconsolidated sand and gravel of the Santa Fe formation. Inasmuch as the long spurs described above are also cut on the Santa Fe formation, the name Cañada Mariana has been applied rather than Rito Leche.

On the west side of the Rio Puerco north of the Rio San José the Cañada Mariana surface is more extensively preserved. It is cut on both the Santa Fe formation and the Cretaceous rocks and is graded to the major tributaries of the Rio Puerco in this region as well as to the Rio Puerco itself. A profile on a long spur in T.10N., R.1W., sloping eastward toward the Rio Puerco shows that this surface was formed when the grade lines were 60 feet higher than the present valley floors. Those remnants close to the Rio Puerco are capped by 10 to 20 feet of cemented gravel. Elsewhere the remnants have a thin gravel cover which is weakly calichified.

At the northern end of the Lower Rio Puerco area are some high, flat-topped, gravel-covered ridges sloping west from the scarp of the Ceja. The projected profiles of these remnants are about 175 feet above the present Rio Puerco valley floor. The erosion surface represented by these remnants may be correlated with the Valle de Parida surface to the south. It also may be correlated with the La Jara surface (180 to 200 feet) of the upper Rio Puerco (Bryan and McCann, 1936).

In addition to the 60-foot Cañada Mariana surface and the 175-foot Valle de Parida surface in this region there are small remnants of a 30-foot surface. These, however, were not mapped. Along the upper Rio Puerco Bryan and McCann (1936) found a 30-foot and a 10-foot terrace.

Along the Rio San José.—For most of the distance from the Zuñi Mountains to the Rio Puerco, the valley of the Rio San José is occupied by flows of basalt through which the river has cut a gorge at least 100 feet deep. Nichols (1933) has distinguished three different lava flows in the San José valley.

The oldest, the Laguna flow, originated west of Laguna Pueblo and flowed at least 20 miles down the narrow Rio San José valley. The next, the Suwanee flow, originated in Cerro Verde, in the southwestern part of the Lower Rio Puerco area. It flowed northward for about 14 miles to the Rio San José, near Suwanee, and then eastward down the San José for about 12 miles. The youngest of the three, the McCartys flow, contains some of the freshest lava in New Mexico. It originated southeast of the Zuñi Mountains, flowed northward to the Rio San José, and then eastward for about 7 miles.

The Suwanee flow reached the Rio Puerco and caused that stream to shift its course 1 to 3 miles to the east. Subsequent dissection by the Rio Puerco has left a small remnant of the caliche-capped erosion surface which was being formed when the Suwanee flow entered the valley. This small remnant (Qsu on Plate 10) has a slope to the west although it is on the west side of the present Rio Puerco. It was therefore formed when the Rio Puerco was in the position now occupied by the flow. The thin

edge of the flow has been eroded back several hundreds of feet, and the old erosion surface thereby exposed has been lowered. In this way the westward slope of this remnant has been increased.

The erosion surface beneath the Suwanee basalt is at least 100 feet above the present elevation of the Rio San José. This surface, here called the Suwanee surface, is probably best correlated with the Cañada Mariana surface (60 feet) of the Rio Puerco valley. Since it is higher it may be slightly older. The time of extrusion of lava has no direct relation to the time of major changes in base level.

The Suwanee flow may be traced back to its source in Cerro Verde, which rises 1000 feet above the surrounding country (Pl. 4, fig. 2). Many of the primary irregularities of the surface of the lava flow have not been removed, although the freshness does not compare with that of the Cat Hills on the Llano de Albuquerque, or that of McCartys flow.

Four miles north of Cerro Verde a tributary to the Arroyo Colorado has cut a canyon about 200 feet deep into the Suwanee basalt. The Suwanee flow here therefore rests on a higher erosion surface than it does near Suwanee. This surface, called the Mush Mesa surface, is 300 to 400 feet below the Ortiz surface, which here is represented by Carlos Mesa and Mesa del Oro, north and west of Cerro Verde respectively. In this region it is cut mostly on the sills which are interbedded in the Triassic rocks.

West of Cerro Verde the Mush Mesa surface is represented by several basalt-capped mesas, the largest of which are Burro Mesa, Mush Mesa, Gunn Mesa, Analla Mesa, and Cold Canyon Mesa. Each is 1 or 2 square miles in area and is surrounded by an apron of landslide debris. Each mesa basalt has its own cinder cone or plug associated with it.

These small remnants all stand about 200 feet above the level of the Arroyo Colorado valley. The Mush Mesa surface, which they represent, is therefore tentatively correlated with the Valle de Parida surface of the Rio Puerco valley.

The lowland west of the Lucero uplift has apparently been a lowland ever since Triassic rocks were exposed there in late Santa Fe time. In Ortiz time the lowland was occupied by the hypothetical Rio del Oro, and the basalt of Mesa del Oro flowed northward down the valley. Dissection of the Ortiz surface produced the Mush Mesa surface, 300–400 feet lower. Basaltic lava was extruded on this surface from many local centers. Such local flows caused slight changes in drainage. When dissection of the Mush Mesa surface commenced after further changes in base level, it was concentrated on the western part of the Arroyo Colorado valley. The eastern part, now occupied by Cerro Verde, was not dissected so readily, partly because of the presence of sills interbedded in the Triassic rocks in this region, and partly because of the proximity of Cinder Butte, one of the Mush Mesa basalts, to Carlos Mesa, which was an Ortiz remnant rising above the Mush Mesa surface. Consequently, when Cerro Verde erupted in Suwanee time the lava flowed out onto the Mush Mesa surface (and is therefore labeled Qmmb on Plate 10). It flowed a short distance west to Cinder Butte, thereby damming a small area between Cinder Butte and the north end of Mesa del Oro and causing its alluviation. (*Note* meanders in the stream.) The basalt from Cerro Verde then flowed northward over a

gentle break in slope onto the Suwanee surface, which it covered for the 22 miles to the Rio Puerco.

A second change in base level of 50–100 feet caused the dissection of the Suwanee surface and the development of the present canyon of the Rio San José.

SPRINGS AND TRAVERTINE DEPOSITS

Every canyon which cuts through the hogbacks east of Lucero Mesa is marked by salt springs. From Highway 6 and the railroad the travertine deposited by these springs appears as large glistening white patches.

The springs are associated with the Lucero fault zone, which was formed in the early Tertiary, but are all located a few hundred feet upstream from the westernmost fault. No springs are associated with the late Tertiary Carrizo fault, at the eastern edge of the Lucero zone. The springs were active at least as early as late Santa Fe time (late Pliocene), for pebbles of travertine are present in the upper member of the Santa Fe formation. In the early Pleistocene they caused the deposition of 100–150 feet of travertine and travertinous gravel on the Ortiz erosion surface. This surface now stands 500–1000 feet above the present level of erosion. Travertine caps the northern end of Mesa del Oro, 25 miles west of the Lucero fault zone. However, still farther west springs even now are depositing travertine. Therefore all the springs are not associated with the Lucero fault zone. Some may not be associated with faults at all.

Samples of spring water were collected from all the larger canyons in the Lucero fault zone and from springs in the Arroyo Colorado valley to the west. The location of each sample is noted on the geomorphic map (Pl. 10) and is described in Table 6. The water analyses (Table 7) were made by the U. S. Geological Survey, W. D. Collins, Chemist in Charge, Quality of Water Division.

Among the samples taken from the Lucero fault zone, there seems to be no consistent influence of the source rock on the composition of the waters. The southern three samples came from the Magdalena formation. Northward the springs emerge from successively younger formations, and the northernmost of the series is in the Mancos shale. The high content of salts in these springs is a result of movement of the water through Carboniferous limestone and gypsum. No discrete beds of salt were found in the Permian of this region, but the gypsum and red beds undoubtedly contain a large amount of salt.

The springs on the Lucero fault zone are small seeps in the canyon bottoms or, in a few cases, in the canyon walls. The flow from a single seep averages only about 0.5 gallon per minute, but the total for any of the larger canyons is about 5 gallons per minute. The samples were taken from the seep farthest upstream, except in the case of nos. 184b and 184c. The seeps, quiet or bubbling, form pools covered by a crust or scum of yellow and green algae. The water tastes salty, and in some cases also alkaline so that stock will not touch it. No vegetation is supported (except algae and small patches of salt grass), chiefly because the water is confined to the flood-scarred canyon bottoms. One spring, however, no. 189, is marked by a cottonwood tree.

Sample no. 194 was taken from the north flank of Lucero Mesa and is not salty.

No faults are visible at this locality, and the spring may owe its origin to minor disruption of ground water drainage by landsliding.

Samples nos. 195, 196, and 203 were taken from the Arroyo Lucero valley west of Lucero Mesa. The largest of these is Lucero Spring (no. 203), which has a flow of about 20 gallons per minute. The water has long been used by stock and occasionally by the local people. A low mound of travertine and cemented wind-blown sand has been formed around it. The springs of this region are not associated with any known faults.

Although Recent volcanic action has occurred in the region east of the Zuñi Mountains and perhaps in the Cat Hills on the Llano de Albuquerque, there is no evidence that the Lucero anticline is underlain by magma at a shallow depth. Therefore the high temperature of the water in the Lucero springs must be due to its deep source. The average temperature of the water is 76°F., or 21°F. above the mean annual temperature of the region. If the thermal gradient is 1° F. per 100 feet, then the water must come from a depth of at least 2100 feet. Since the region is in the Rio Grande drainage area, the ground water presumably flows eastward under artesian conditions and rises along the Lucero fault zone. It is not known what produced the artesian conditions. The fault zone is located near the crest of the Lucero anticline, so the beds on the west limb would carry water away from the fault zone rather than toward it. East of the fault zone is the Santa Fe formation. Perhaps the abundance of relatively impermeable silt and clay in the playa deposits in the Santa Fe in this region produced an effective dam to the eastward flow of the water, which was thereby forced to rise on the Lucero fault zone.

LANDSLIDES

Landsliding is well displayed in the western part of the area on those mesas or parts of mesas which are made of Triassic shale capped by basalt or travertine. The most spectacular development is on the western edge of Mesa del Oro, where the blocks start as strips of the basalt cap 150 feet thick, as much as 3 miles long, and only a few hundred feet broad. Similar landslide strips on the northern part of Lucero Mesa are ¼–1½ miles long (Pl. 5). The strips are separated originally from the unbroken basalt capping by crevices only a few feet wide but more than 75 feet deep (Pl. 6, fig. 1). As they slide down the slope of the mesa, the spaces between blocks become filled with talus and alluvium. The blocks finally break up into great heaps of angular boulders, and streams coming off the mesa have adjusted their courses to the irregular masses of old landslide debris. The presence of fresh crevices on the edges of the mesas indicates that landsliding is still going on in this region, but it was probably much more active in the Pleistocene, when the wetter climate produced a higher water table.

WIND-BLOWN SAND

The largest area of wind-blown sand is on the Llano de Albuquerque and the terraces which border it on the east. Cliff dunes with a maximum height of 60 feet fringe

TABLE 6.—*Description of spring water samples*

No. on Plate 10	Location			Distance from No. 171 in miles	Temp. in °F.	Flow Gallons per minute	Flow in whole canyon Gallons per minute	Formations	No.
			LUCERO FAULT ZONE SPRINGS						
171	T5N R3W	SE¼	sec. 29 Ar. Coyote	0	64	0.3	3	Cm	171
172	T6N R3W	SW¼ of SE¼	sec. 35 Ar. Comanche	6	71		5	Cm	172
173	T6N R2W	SE¼ of SW¼	sec. 6 Ar. Carrizo	11.3	78	0.1	5	Cm	173
187	T7N R2W	SE¼ of NW¼	sec. 31 Unnamed canyon	12.7	80	0.05	5	Ca	187
188	T7N R2W	Center of	sec. 30 Unnamed canyon	13.5	86	0.05	5	Ccy	188
189	T7N R2W	SE¼ of NW¼	sec. 30 Unnamed canyon	13.7	75	0.35	5	Cchs	189
184a	T7N R2W	NW¼ of SW¼	sec. 18 Unnamed canyon	15.5	82	0.02	1	Cchs	184a
184b	T7N R2W	NW¼ of SW¼	sec. 18 Unnamed canyon	15.5		0.05	1	TR	184b
184c	T7N R2W	SE¼ of NW¼	sec. 18 Unnamed canyon	15.5		0.2	1	TR	184c
185	T7N R2W	SE¼ of SW¼	sec. 7 Unnamed canyon	16.3		0.05	0.1	TR	185
186	T7N R2W	Center NW¼	sec. 7 Unnamed canyon	17.0	76	0.5	3	TR	186
190	T7N R2W	SW¼ of SE¼	sec. 6 Unnamed canyon	17.5	80	0.5	1	Jm	190
192	T7N R2W	NW¼ of NE¼	sec. 6 Unnamed canyon	18.0		0.3	0.3	Km	192
193	T8N R2W	SE¼ of SW¼	sec. 30 Ar. Garcia	19.5	72	0.3	5	Km	193
210	T8N R2W	SW¼ of SW¼	sec. 20 Escondito Spring	20.7	73	0.02	0.02	Jm	210
			OTHER SPRINGS						
194	T8N R3W	Center NW¼	sec. 35		65	1.0		TR	194
195	T7N R4W	SW¼ of SE¼	sec. 3		65	0.01		TR	195
196	T7N R4W	SW¼ of SE¼	sec. 11 Lucero Spring		62	20		TR	196
203	T7N R5W	SE¼ of SW¼	sec. 20		68	3		TR	203

FORMATIONS:

Cm—Magdalena limestone
Ca—Abo formation
Ccy—Yeso member of Chupadera formation—red sand and gypsum
Cchs—Hondo and San Andres members of Chupadera formation—white sandstone, limestone, and gypsum
TR—Triassic soft shale and sandstone
Jm—Morrison formation—yellow sandstone and dark shale
Km—Mancos shale—yellow shale and sandstone

the western (Ceja) and eastern (Cejita) scarps of the Llano. Most of the cliff dunes have been stablized by vegetation, but some are still active, notably those on the southern edge of the westward-extending promontory of the Llano on the Isleta

TABLE 7.—*Analyses of spring water samples.*

By N. A. Talvitie, U. S. Geological Survey. Figures in parts per million.

No. on Plate 10	171	172	173	184a	184b	184c	185	186	187	188
SiO_2	5.9	15.	21.	34.	—	—	—	37.	20.	—
Fe	.80	.57	.02	1.8	—	—	—	.08	.18	—
Ca	284.	704.	534.	918.	566.	418.	324.	108.	603.	297.
Mg	245.	356.	448.	220.	188.	187.	152.	138.	271.	224.
Na	10,370.	4,570.	3,650.	10,950.	—	—	—	9,760.	5,230.	—
K	225.	79.	38.	283.	—	—	—	283.	118.	—
HCO_3	2,700.	2,049.	1,385.	2,840.	2,031.	1,607	2,214.	1,713.	1,615	1,374.
SO_4	4,510.	2,660.	2,640.	8,910.	7,390.	8,040	6,670	6,710.	5,380.	6,710.
Cl	12,500.	6,240.	5,160.	11,120.	9,210.	10,160.	9,070.	9,940.	5,120.	8,880.
F	1.6	.0	1.0	3.4	—	—	—	5.8	1.2	—
NO_3	—	—	—	—	—	—	—	—	—	—
Total dissolved solids	29,500.	15,630.	13,540.	33,900.	27,800.	30,000.	26,700.	27,900.	17,540.	25,700.
Total hardness as $CaCO_3$	1,716.	3,220.	3,170.	3,200.	—	—	—	837.	2,620.	—
Density*	1.020	1.010	1.008	1.023	1.018	1.019	1.017	1.019	1.011	1.016

No. on Plate 10	189	190	192	193	194	195	196	203	210
SiO_2	32.	—	—	20.	28.	—	20.	—	12.
Fe	15.	—	—	.09	.02	—	1.4	—	.02
Ca	702.	312.	227.	516.	65.	606.	640.	604.	33.
Mg	214.	133.	185.	163.	18.	150.	177.	130.	20.
Na	6,470	—	—	6,630	43.	—	301.	—	23.
K	165.	—	—	194.	3.9	—	26.	—	5.6
HCO_3	2,174.	2,099.	2,047.	1,345.	377.	408.	625.	428.	220.
SO_4	5,640.	6,380.	7,800.	6,540.	13.	1,969.	1,957.	2,010.	32.
Cl	6,560.	9,600.	11,560.	6,170.	3.1	146.	326.	113.	5.6
F	2.8	—	—	4.3	.2	—	1.0	—	.7
NO_3	—	—	—	—	.83	—	—	—	.10
Total dissolved solids	20,920.	27,100.	32,400.	20,900.	355.	3,440.	4,010.	3,500.	239.
Total hardness as $CaCO_3$	2,630.	—	—	1,958.	236.	—	2,325.	—	164.
Density*	1.014	1.018	1.021	1.013	—				

* Weight in air (in grams) of 1 ml. at 27° C.

Reservation. The sand was derived from the floodplain of the Rio Puerco and the dissected Santa Fe formation between the floodplain and the Ceja.

Extending eastward from the cliff dunes of the Llano, especially on the Isleta Reservation, are belts of longitudinal, parabolic, and transverse dunes. Their forms indicate a dominant wind from S.75° W. The dunes have modified the stream pattern slightly, and in places have completely obliterated scarps and other stream-formed features. They are now largely inactive, but they cover and are thus younger than the fresh lava of the Cat Hills.

Other areas of wind-blown sand are the valley of Arroyo Colorado and the dissected erosion surfaces north of the Rio San José.

SUMMARY OF GEOMORPHIC HISTORY

Following the deformation of the Santa Fe formation at the end of the Tertiary, the extensive Ortiz erosion surface was cut in the Albuquerque-Belen basin and

Cchs—Ronco and San Andres members of Chupadera formation—white sandstone, limestone, and gypsum

adjacent highlands. It was graded to a level 400–500 feet above the present Rio Grande. Subsequent changes in base level brought about the dissection of the Ortiz surface, the inception of the Rio Puerco by piracy, and the formation of erosional terraces along the three principal rivers of the area, namely the Rio Grande, Rio Puerco, and Rio San José. Within the Lower Rio Puerco area these were the Cochiti, Valle de Parida, and Mush Mesa surfaces 175–200 feet above the modern rivers, the Segundo Alto at 125 feet, and the Llano de Sandia, Cañada Mariana, and Suwanee at 50–100 feet. Just east and south of the area are the La Bajada and Tio Bartolo surfaces at 250–300 feet.

The erosion surfaces were covered during or after their formation by stream gravel, caliche, wind-blown sand, travertine, or basaltic lava. Some of the sand dunes are still active as are also some of the thermal salt springs which produced the travertine. The surfaces are being reduced by stream action and in some cases by extensive landsliding. The modern streams are cutting arroyos in their most recent floodplains.

REFERENCES CITED

Baker, A. A., Dane, C. H., and Reeside, J. B., Jr. (1936) *Correlation of Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado*, U. S. Geol. Survey, Prof. Paper 183.

Bryan, Kirk (1909) *Geology of the vicinity of Albuquerque, New Mexico*, Univ. N. Mex., Bull. 3, p. 1–24.

——— (1932) *Pediments developed in basins with through drainage as illustrated by the Socorro area, N. Mex.* (Abstract), Geol. Soc. Am., Bull., vol. 43, p. 128–129.

——— (1938) *Geology and ground water conditions of the Rio Grande depression in Colorado and New Mexico*, Regional Planning, pt. 6, Rio Grande Joint Investigation in the Upper Rio Grande Basin (Washington: National Resources Committee), vol. 1, pt. 2, sec. 1, p. 197–225.

——— and McCann, F. T. (1936) *Successive pediments and terraces of the upper Rio Puerco in New Mexico*, Jour. Geol., vol. 44, p. 145–172.

——— (1937) *The Ceja del Rio Puerco: a border feature of the Basin and Range province in New Mexico, Part I, Stratigraphy and structure:* Jour. Geol., vol. 45, p. 801–828.

——— (1938) *The Ceja del Rio Puerco: a border feature of the Basin and Range province in New Mexico, Part II, Stratigraphy and structure*, Jour. Geol., vol. 46, p. 1–16.

——— and Upson, J. E., *Geology and geomorphology of the Santo Domingo Valley, New Mexico* (unpublished paper).

Cabot, E. C. (1938) *Fault border of the Sangre de Cristo Mountains north of Santa Fe, New Mexico*, Jour. Geol., vol. 46, p. 88–105.

Church, Fermor, and Hack, John T. (1939) *An exhumed erosion surface in the Jemez Mountains, New Mexico*, Jour. Geol., vol. 47, p. 613–629.

Cloos, Hans (1936) *Einführung in die Geologie*, Borntraeger, Berlin.

Cope, E. D. (1877) *The extinct Vertebrata obtained in New Mexico by parties of the expedition of 1874*, U. S. Geog. Surveys W. 100th Meridian, vol. 4, pt. 2, p. 15–20.

Dane, C. H. (1936) *The La Ventana-Chacra Mesa coal field*, U. S. Geol. Survey, Bull. 860C.

Darton, N. H. (1928) *Redbeds and associated formations in New Mexico*, U. S. Geol. Survey, Bull. 794.

Denny, C. S. (1940a) *Tertiary geology of the San Acacia area, New Mexico*, Jour. Geol., vol. 48, p. 73–106.

——— (1940b) *The Santa Fe formation in the Espanola Valley, New Mexico*, Geol. Soc. Am., Bull., vol. 51, p. 677–694.

——— (1941) *Quaternary geology of the San Acacia area, New Mexico*, Jour. Geol., vol. 49, p. 225–260.

Dunham, K. C. (1935) *Geology of the Organ Mountains, New Mexico*, N. Mex. School Mines, Bull. 11.

Fath, A. C. (1920) *The origin of the faults, anticlines, and the buried "granite ridges" in the northern part of the mid-continent oil and gas field*, U. S. Geol. Survey, Prof. Paper 128C.

Frick, Childs (1937) *The horned ruminants*, Am. Mus. Nat. Hist., Bull., vol. 69, p. 6.

Gilbert, G. K. (1875) *Report on the geology of portions of New Mexico and Arizona examined in 1873*, U. S. Geog. Surveys W. 100th Meridian, vol. 3, p. 520–521.

Hayden, F. V. (1869) *Preliminary field report of the U. S. Geological Survey of Colorado and New Mexico*, U. S. Geog. Geol. Survey Terr., 3rd Ann. Rept., p. 166–170.

Herrick, C. L. (1898a) *Geology of the environs of Albuquerque, New Mexico*, Am. Geol., vol. 22, p. 26–43.

——— (1898b) *Papers on the geology of New Mexico*, Denison Univ., Sci. Lab., Bull., vol. 11, p. 75–94.

——— (1900) *Reports of a geological reconnaissance in western Socorro and Valencia Counties, New Mexico*, Am. Geol., vol. 25, p. 331–346.

——— and Johnson, D. W. (1900) *Geology of the Albuquerque sheet*, Denison Univ., Sci. Lab., Bull., vol. 11, p. 176–240.

Hunt, C. B. (1936) *The Mount Taylor coal field*, U. S. Geol. Survey, Bull. 860B.

——— (1938) *Igneous geology and structure of the Mount Taylor volcanic field*, U. S. Geol. Survey, Prof. Paper 189B.

Johnson, D. W. (1903) *Block mountains in New Mexico*, Am. Geol., vol. 31, p. 137.

——— (1907) *Volcanic necks of the Mount Taylor region, New Mexico*, Geol. Soc. Am., Bull., vol. 18, p. 303–324.

King, P. B. (1942) *The Permian of West Texas and New Mexico*, Am. Assoc. Petrol. Geol., Bull., vol. 26, p. 535–711.

Lang, W. B. (1937) *Permian formations of the Pecos Valley*, Am. Assoc. Petrol. Geol., Bull., vol. 21, p. 833–898.

Lasky, S. G. (1938) *Geology and ore deposits of the Lordsburg Mining District, Hidalgo County, New Mexico*, U. S. Geol. Survey, Bull. 885.

Lee, W. T. (1907) *Water resources of the Rio Grande Valley and their development*, U. S. Geol. Survey, W.-S. Paper 188.

——— (1926) *Relations of Cretaceous formations to the Rocky Mountains in Colorado and New Mexico*, U. S. Geol. Survey, Prof. Paper 95.

McCann, F. T. (1938) *Ancient erosion surface in the Gallup-Zuñi area, New Mexico*, Am. Jour. Sci., 5th ser., vol. 36, p. 260–278.

Nichols, R. L. (1933) *Quaternary geology of the San José Valley, New Mexico* (Abstract), Geol. Soc. Am., Pr. 1932, p. 453.

Ogilvie, Ida H. (1905) *The high-altitude conoplain: a topographic form illustrated in the Ortiz Mountains, New Mexico*, Am. Geol., vol. 36, p. 27–34.

Price, W. A. (1933) *The Reynosa problem of South Texas and the origin of caliche*, Am. Assoc. Petrol. Geol., Bull., vol. 17, p. 488–522, and discussion, p. 1277–1281.

Reeside, J. B. (1924) *Upper Cretaceous and Tertiary formations of western part of the San Juan Basin, Colorado and New Mexico*, U. S. Geol. Survey, Prof. Paper 134.

Renick, B. C. (1931) *Geology and ground water resources of western Sandoval County, New Mexico*, U. S. Geol. Survey, W.-S. Paper 620.

Sears, J. D., Hunt, C. B., and Hendricks, T. A. (1941) *Transgressive and regressive deposits in the southern San Juan Basin, New Mexico*, U. S. Geol. Survey, Prof. Paper, 193F.

Smith, H. T. U. (1938) *Tertiary geology of the Abiquiu quadrangle, New Mexico*, Jour. Geol., vol. 46, p. 933–965.

Stark, J. T., and Dapples, E. C. (1941) *Structure of the Los Pinos Mountains, New Mexico* (Abstract), Geol. Soc. Am., Bull., vol. 52, p. 1936.

Stearns, C. S. (1943) *The Galisteo formation in north-central New Mexico*, Jour. Geol., vol. 51, p. 301–319.

——— *Geology of the Galisteo-Tonque area, New Mexico* (in preparation).

Thompson, D. G. (1929) *The Mohave Desert region, California*, U. S. Geol. Survey, W.-S. Paper 578.

Wells, E. H. (1919) *Oil and gas possibilities of the Puertecito district, Socorro and Valencia Counties, New Mexico*, N. Mex. School Mines, Bull. 3.

Winchester, D. E. (1920) *Geology of the Alamosa Creek Valley, Socorro County, New Mexico*, U. S. Geol. Survey, Bull. 716a.

Woolnough, W. G. (1928) *Origin of white clays and bauxite, and chemical criteria of peneplanation*, Econ. Geol., vol. 23, p. 887–894.

Wright, H. E. (1943) *Cerro Colorado, an isolated non-basaltic volcano in central New Mexico*, Am. Jour. Sci., vol. 241, p. 43–56.

Brown University, Providence, R. I.

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S. Paper

Counties,

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Mexico,

GEOMORPHIC MAP OF THE LOWER RIO PUERCO AREA, NEW MEXICO

By H.E. Wright, 1940-41, assisted by J.W. Dow, R.C. Bryan and G.J. Lyons

EXPLANATION

- Qal — Alluvium of recent streams
- Qls — Landslide debris
- Qs — Wind-blown sand
- Qtr — Travertine
- Qb — Basalt

(On undifferentiated erosion surfaces)

- Fault; only post-Santa Fe border faults and Ortiz faults shown.
- Contact between stratigraphic and geomorphic units
- Scarp
- Ranch
- Town or railroad station
- Locality of spring water sample
- Township corner

DISSECTED EROSION SURFACES COVERED BY:

Location	Gravel and/or caliche	Wind-blown sand	Basalt	Travertine	Name	Height above present grade
Rio Grande	Qlds				Llano de Sandia	50-75 feet
Rio Puerco	Qcm	Qcms			Cañada Mariana	60
Rio San José	Qsu		Qsub		Suwanee	50-100
Rio Grande	Qse	Qses	Qseb		Segundo Alto	125
Rio Grande	Qc				Cochiti	200
Rio Puerco	Qvp			Qvpt	Valle de Parida	175
Rio San José	Qmm				Mush Mesa	200
Rio Grande	Qa	Qas	Qab	Qat	Ortiz	400-500

Quaternary / Tertiary

- TQi — Intrusives of several ages
- Tsf | Tsfb — Santa Fe formation, with interbedded basalt
- Tmv — Miocene (?) non-basaltic volcanics
- pT — Pre-Tertiary rocks undifferentiated

Base map compiled from aerial photographs.

Scale in Miles: 0 2 4 6 8

R 6 W · R 5 W · R 3 W · R 2 W · R 1 W · R 1 E

107°30' · 107°15' · 107°00' · 106°45'

35°15' · 35°00' · 34°45'

T 11 N · T 10 N · T 9 N · T 8 N · T 7 N · T 6 N · T 5 N · T 4 N

SANDOVAL COUNTY · BERNALILLO COUNTY · VALENCIA COUNTY · SOCORRO COUNTY

Albuquerque · Isleta · Los Lunas · Rio Puerco Station · Atchison · Topeka & Santa Fe · Wilson · Harrington · Suwanee · Carrie · Garcia · Jarales · Dalen · Pino · Payne · Huning

U. S. Hwy. 66 · State Hwy. 6 · State Hwy. 85

Cañada del Maple · Arroyo Gigante · Mesa Rosario · Arroyo Lucero · Arroyo Cocina · Arroyo Apache · Arroyo Garcia · Arroyo Carrizo · Arroyo Alamo · Cerro Colorado · Cerros Molinos · Badlands · Gabaldon · Cimarron Mesa · Valles Mesa · Gallina Mesa · Carlos Mesa · Cold Canyon Mesa · Pelado Mesa · Petaca Pinta · Petoch Butte · Anell Mesa · Doe Mtn. · Cerro Negro · Cerro Montoso · Cañada Coyote · Cañada de Pedro · Arroyo Seco · Water Creek · Badger Wash · Sand Hill fault · Rio Puerco · Rio Grande · Rio Albuquerque · Rio Blanco · Rio San José · Rio Puerco de Belen · Los Lunas Lateral · Mesa Prieta · Mesa de Los Lunas · Mesa de Los Cellis

Qb/o Basalt

• 184 Locality of spring water sample

+ Township corner

DISSECTED EROSION SURFACES COVERED BY:

	Location	Gravel and/or caliche	Wind-blown sand	Basalt	Travertine	Name	Height above present grade
Quaternary	Rio Grande	Qlds				Llano de Sandia	50-75 feet
	Rio Puerco	Qcm	Qcms			Cañada Mariana	60
	Rio San José	Qsu		Qsub		Suwanee	50-100
	Rio Grande	Qa4	Qas3	Qab3		Segundo Alto	125
	Rio Grande	Qa				Cochiti	200
	Rio Puerco	Qvp			Qvtr	Valle de Parida	175
	Rio San José	Qmm				Mush Mesa	200
	Rio Grande	Qo	Qos	Qob	Qotr	Ortiz	400-500

TQi Intrusives of several ages

Tsf Tsfb Santa Fe formation, with interbedded basalt

Tmv Miocene (?) non-basaltic volcanics

pT Pre-Tertiary rocks undifferentiated

Base map compiled from aerial photographs.

Scale in Miles 0 2 4 6 8

BERNALILLO COUNTY
VALENCIA COUNTY
VALENCIA COUNTY
SOCORRO COUNTY

T11N T10N T9N T8N T7N T6N T5N T4N

35°00' 34°45' 34°30'

107°30' 107°15' 107°00' 106°45'

R6W R5W R3W R2W R1W R1E

GEOMORPHIC MAP OF LOWER RIO PUERCO AREA

Abs
Intr
Ack
Top
Gen
Des

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CRYSTALLINE ROCKS OF SOUTHERN CALIFORNIA

BY WILLIAM J. MILLER

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ABSTRACT

The crystalline rocks which occupy most of the 40,000 square miles of southern California range in age from Early pre-Cambrian to Quaternary. They include metasediments, plutonics, migmatites, complexes, volcanics, metavolcanics, and dikes.

Principal attention is given to the kinds, ages, origin, emplacement, distribution,

and correlation of the widespread crystalline rocks. Thirty large areas, representing all important parts of southern California, have been chosen for special study and description. The writer has carried on field work in all these areas, has published papers on eight of them, and describes five of them here for the first time. Ten of the areas have been in part published upon by other workers, and in part reported on by the writer here for the first time. Seven of the areas have been more or less fully published upon by others. The work of others is critically reviewed, and various changes have been made in the light of field and laboratory work by the writer.

A chart, representing a more or less preliminary correlation of the principal crystalline rock units of the 30 areas, accompanies the paper. Correlational problems are discussed at length. The occurrence of fossils in various metasedimentary formations has greatly aided in the age determination of associated igneous rocks.

Another chart shows 29 chemical analyses of carefully selected igneous rocks, and their calculated modes and norms. Petrographic descriptions of these rocks are given.

INTRODUCTION

For more than 21 years the writer's principal research interest has been a study of the crystalline rocks widely exposed over an area of 40,000 square miles of southern California. Nearly every important part of this large region has been visited and examined in varying degrees of detail. The writer has mapped in detail various carefully selected, widely distributed, key areas, comprising a total of approximately 4300 square miles and has published papers upon them. Many important, unpublished field and laboratory notes are made use of in the present paper. The accomplishment of this purpose has involved many thousands of miles of footwork and extensive use of the automobile. Thousands of specimens have been collected and studied in the laboratory. Many hundreds of thin sections have been examined. Chemical analyses of 29 carefully selected plutonic and dike rocks have been made for the writer. These and their calculated norms are published here for the first time.

Various papers published by other workers include important data on the crystalline rocks of southern California. Such work is fully credited in the following regional descriptions and discussions. The pioneer publication by Hershey (1902a) deserves special mention. In this paper, based upon reconnaissance field work, important groups of crystalline rocks in Los Angeles County, southeastern Kern County, and western San Bernardino County are described and tentatively correlated.

Most of the rock successions and correlations set forth in the present paper are believed to be largely correct. Age determination of a number of important metasedimentary formations has been made possible by fossils found by several workers, including the writer. In various cases, however, anything like definite ages of formations cannot for the present be given. Practically all the literature of the extensive region is familiar to the writer, who also has first-hand knowledge of the areas discussed. In most of these areas geologic field work has been done in sufficient detail to warrant conclusions in regard to kinds, distribution, structures, emplacement, and relative ages of the rock units. A tentative correlation table of all important crystalline-rock units and formations is presented, and correlation problems are discussed.

ACKNOWLEDGMENTS

Generous grants in aid have been received each year during the last 20 years from the Board of Research of the University of California, Los Angeles. These funds have covered the cost of the chemical analyses and the thin sections, and much of the cost of the field work. This aid is here gratefully acknowledged.

The writer is particularly indebted to Dr. R. W. Webb of the Geology Department, University of California, Los Angeles, for his company on various field trips and for many discussions in the laboratory.

The late Professor John E. Wolff, formerly of Harvard University, accompanied the writer on several field trips and helped with a number of thin sections during the first years of the project.

Dr. Cordell Durrell of the Geology Department, University of California, Los Angeles, has kindly helped with the interpretation of various thin sections, particularly of the metavolcanics.

During the 21 years, many advanced students in the Geology Department of the University of California have accompanied the writer on field trips to various parts of southern California and prepared theses under his direction on many local areas of crystalline rocks near Los Angeles. Those deserving special mention in this connection are Robert Webb, Vincent Kelley, Earl Irving, Robert Bryson, Robert Townsend, and Stanley Mitchell.

TOPOGRAPHIC FEATURES

Generally considered, the 40,000 square-mile region covered in this paper is very mountainous. The locations of the principal mountains, as well as of many of the cities and towns, are shown on the accompanying map (Pl. 1) of the region. Altitudes range from 244 feet below sea level at the Salton Sea to 11,485 feet in the San Bernardino Mountains. Nearly all the mountains shown on the map rise 1000 to 10,000 feet above the surrounding country.

The highest mountains are in the western and southwestern part of the region considered in this paper. Most important among these, with maximum altitudes, are: southern Sierra Nevada (Sirretta Pk., 9956 feet, 16 miles north-northeast of Kernville); Tehachapi Mountains (nearly 8000 feet); San Gabriel Mountains (Mt. San Antonio, 10,080 feet); San Bernardino Mountains (San Gorgonio Mtn., 11,485 feet); San Jacinto Mountsins (San Jacinto Pk., 10,805 feet); Santa Rosa Mountains (Toro Pk., 8705 feet); and Peninsular Mountains (Cuyamaca Pk., 6515 feet). These mountains are, in the normal cycle of erosion, in stages varying from late youth to early maturity.

East of the mountains above listed, the middle-northern and northeastern parts of the map area (Pl. 1) is known as the Mohave (or Mojave) Desert and the southeastern part is known as the Colorado Desert. Throughout these desert regions, rough, rocky mountains rise steeply 1000 to 3000 feet above adjacent valley floors which have relatively smooth surfaces and gentle slopes. The broad, heavily alluviated valley floors comprise more than half the total area of the two deserts. More or less extensive and conspicuous alluvial fans everywhere extend out, often for miles, from

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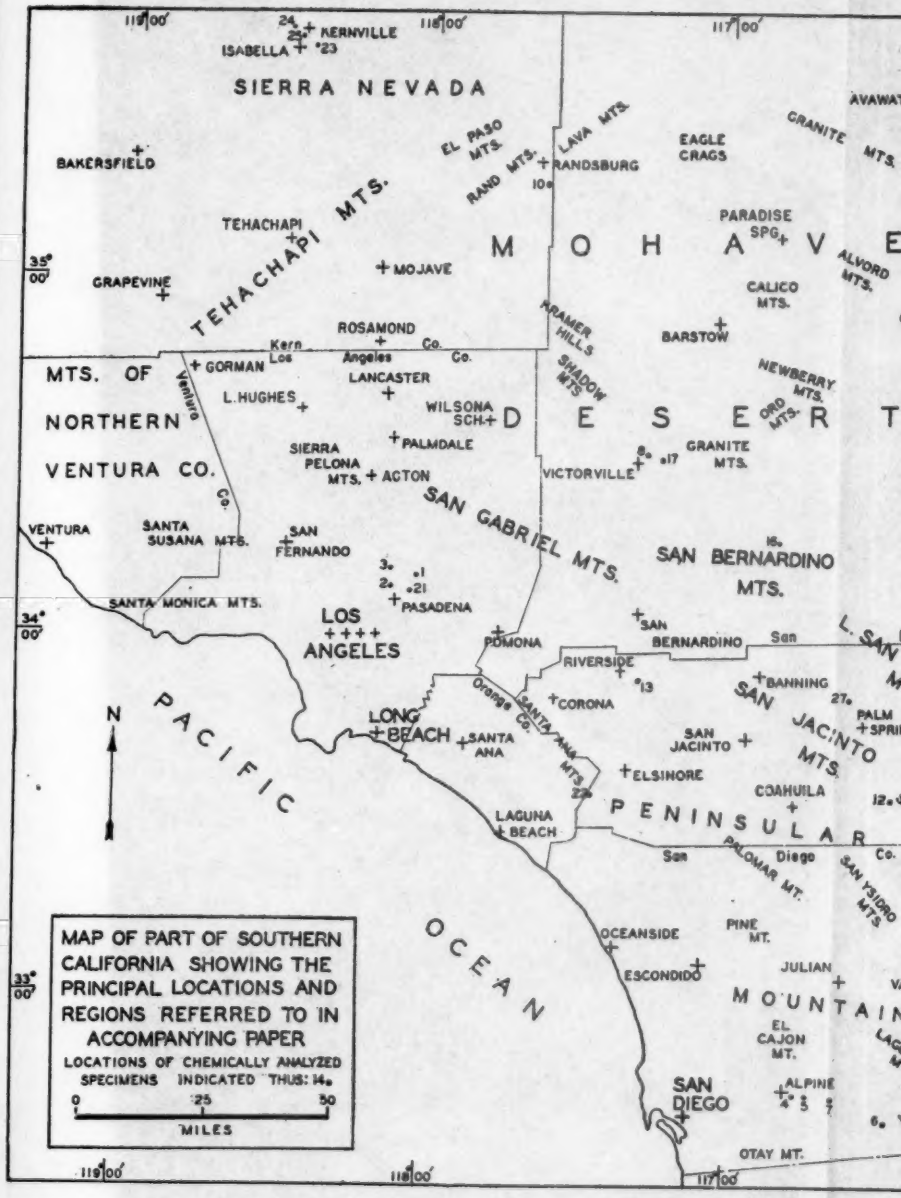

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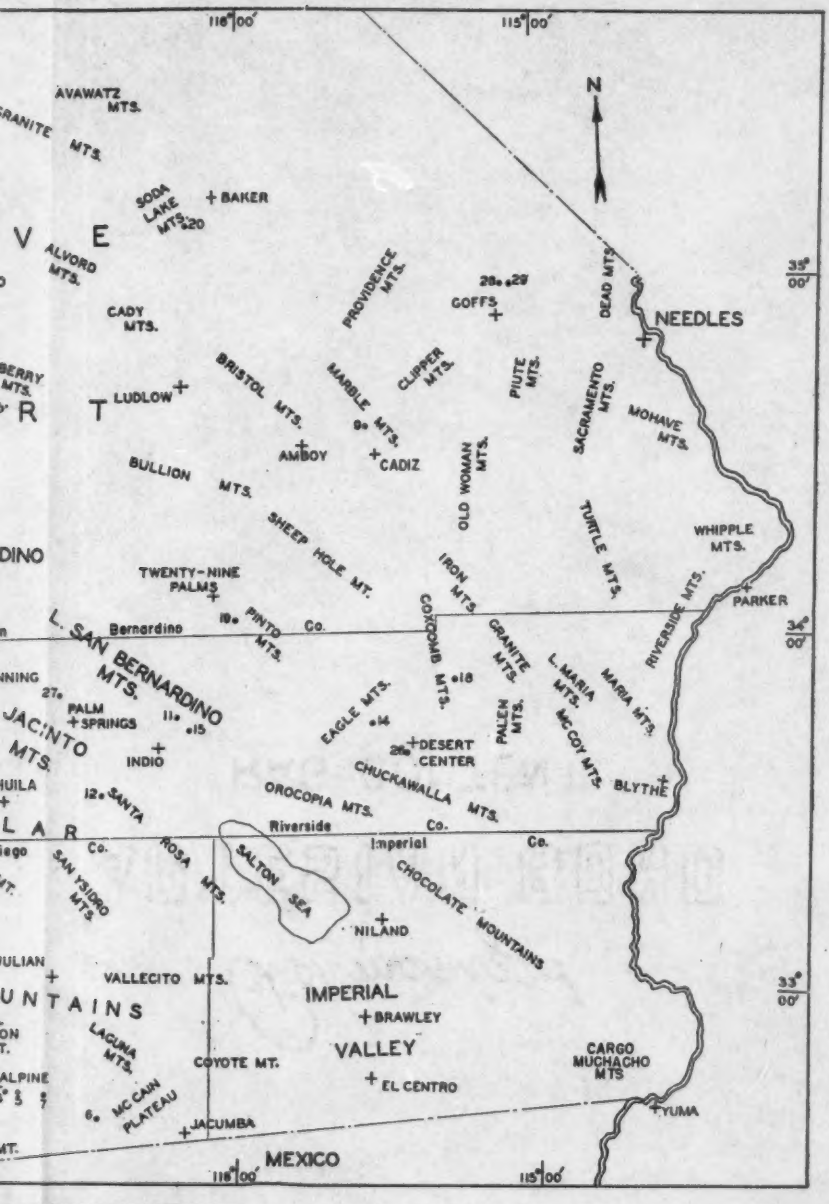

UTHERN CALIFORNIA

the mountain bases. Topographically, the whole desert region represents stages varying from early maturity to early old age in the desert cycle of erosion.

The prevailing trend of mountain ranges in southern California is northwesterly. The most important exceptions are the southern Sierra Nevada, including the Tehachapi Mountains, which run nearly north-south, and the east-west trending so-called Transverse Ranges, including the Santa Monica Mountains and others just north of them, the San Gabriel Mountains, and the San Bernardino Mountains.

The present-day mountains and intermont valleys of southern California owe their existence very largely to Late Cenozoic faulting which, in many places, is still active. The great San Andreas fault cuts northwesterly through the region. The general significance of faulting in southern California has been discussed (Miller, 1940).

GENERAL LITHOLOGIC FEATURES

Omitting the widespread, unconsolidated Quaternary deposits, the 40,000 square-mile region of southern California consists very largely of crystalline rocks. Some areas of nonmarine, later Tertiary strata are scattered through the Mohave and Colorado deserts. In the western and southwestern parts of the region, the higher mountains are almost entirely crystalline rocks. West of the higher mountains and forming the western border of the whole region, Tertiary strata (mostly marine), together with some Late Cretaceous strata and Middle and Late Tertiary volcanics, are the prevalent rocks. These are most widely exposed in the middle-western border of the region, northwest and southeast of Los Angeles. The 1938 Geologic Map of California published by the Division of Mines of the State of California gives a good general idea of the distribution of the rocks of southern California.

The crystalline rocks of southern California range in age from Early pre-Cambrian to Quaternary. They are very extensive and unusually well exposed, particularly in the desert and semidesert mountains. Many of the rock units are widespread, often as extensive areas, while others are much restricted in distribution and extent of areas. The crystalline rocks include plutonics, migmatites, dikes, metasediments, metavolcanics, and volcanics.

The oldest rocks, believed to be older pre-Cambrian, are, in order of age, metasediments, diorite and metadiorite, granite, mixed rocks (migmatites, etc.), and anorthosite. Except for the anorthosite, these rocks are widely distributed.

The younger pre-Cambrian is represented by several important areas of metasediments, mainly mica schists.

Definitely known Paleozoic metasediments include several small areas of Cambrian in the northern part of the region, and various widely scattered, small and fairly large areas of Late Paleozoic or Carboniferous, and possibly some middle Paleozoic.

Of probable Paleozoic age are some areas of metasediments. Paleozoic or early Mesozoic metasediments, associated with varying amounts of metavolcanics, occupy a number of important areas.

Various large and small areas of Paleozoic and/or Mesozoic complexes consist of metasediments more or less intimately cut and injected with granitic material.

Some large and small areas of moderately metamorphosed Triassic and probable Triassic strata occur, especially in the Peninsular Mountains.

Many small to fairly large bodies of pre-Tertiary, generally massive, but locally well foliated gabbro, diorite, and quartz diorite, all closely related in age, occur in various parts of the region. Most of these are believed to be of Late Mesozoic age, but some may be Late Paleozoic.

A large number of small to large stocks and batholiths of quartz diorite and quartz monzonite, with facies varying to gabbro-diorite and to granite, are widely distributed throughout southern California. These are quite certainly of Late Mesozoic age and for most part genetically related to the gabbros and diorites above mentioned, with the acidic intrusives representing the later intrusions from a common source magma.

Basic and acidic dikes of Middle Tertiary age occur in many parts of the region and cut the older rocks sharply.

Tertiary volcanics, both lavas and pyroclastics, mainly of Miocene age, are widespread, particularly in the Mohave and Colorado deserts.

Several small batholiths of Tertiary granite are shown on the 1938 geologic map of California. In the writer's opinion their Tertiary age is doubtful, and they are more likely Late Mesozoic or in part even still older.

Quaternary volcanics occur in some widely scattered areas.

DESCRIPTIONS OF AREAS

GENERAL STATEMENT

The purpose of the areal descriptions is to set before the reader the more important data on the crystalline rocks of southern California. The 30 areas carefully selected for description are widely scattered over the region considered in this paper. These areas are believed to represent nearly all kinds, ages, and relationships of the crystalline rocks. On the basis of such data, a tentative correlation of all known crystalline rocks of southern California is attempted (Table 4).

Ten of the areas have been geologically mapped wholly or in part in considerable detail, and published upon, by the writer. In view of the fact that these important areas have been rather fully reported on, only brief summaries, together with some heretofore unpublished observations, are given.

Ten of the areas have been mapped wholly or in part, and published upon, by others. The writer has gone over all these areas in greater or less detail. Brief summaries, with comments on the work of others, are presented. Also included are observations on parts of these areas not covered in the publications.

Eight of the areas are represented by little or no important published material. Results of field and laboratory work pertaining to these are here presented for the first time.

The southern California portion of the 1938 Geologic Map of California is a great improvement over the 1916 map, but, even so, various areas are left blank, many are much generalized by lumping together important rock units, and still others are wrongly mapped. Many improvements in this mapping have been made by the writer.

SAN GABRIEL MOUNTAINS (WESTERN)

Introduction.—Few if any of the areas of crystalline rocks described in this paper contain a greater variety of important crystalline rocks than the San Gabriel Mountains. These very rugged mountains, covering an area of 1200 square miles, show altitudes commonly varying from 4000 to 10,080 feet, and they rise boldly thousands of feet above the surrounding country. Based upon field and laboratory work carried on mainly between 1924 and 1933, the writer published an elaborate paper (Miller, 1934), accompanied by a geologic map, on the western and middle-southern half of the mountains. The known formations of this area are listed in Table 4.

Pre-Cambrian rocks.—The oldest rocks in the western San Gabriel Mountains are metasediments, the Placerita formation, well shown in the western part of the area, especially in Placerita Canyon. This formation, consisting mainly of interbedded biotite schist, quartzite, quartz-pyroxene gneiss, and fine- to medium-grained crystalline limestone, is at least 5000 feet thick. Little of the formation can be mapped as such because it has nearly everywhere been so thoroughly cut to pieces first by diorite and then by granite, and often injected *lit-par-lit* by the granite, that only small remnants of recognizable metasediments remain in the form of layers, lenses, and shreds.

Next in age is the above-mentioned diorite, varying to hornblendite and metadiorite—the Rubio diorite. It occurs as numerous widely scattered, relatively small bodies, many of which are mappable. These are remnants of once much larger masses left after wholesale attack of granite magma upon both the Placerita metasediments and the Rubio diorite. Chemical analysis, norm, and mode of the diorite from its type locality are given in Table 1 (No. 21).

Both the metasediments and the diorite have been extensively cut to pieces, often injected *lit-par-lit*, and variably digested by what has been called Echo granite, which is usually foliated, granulated, and variably contaminated. Only one fairly large mass of this granite is sufficiently uncontaminated to warrant separate mapping. Chemical analysis, norm, and mode of a specimen of the granite are given in Table 1 (No. 2).

As already suggested, the metasediments, diorite, and granite are very commonly too intimately mixed to permit mapping them separately. This combination of rocks, called the San Gabriel formation (or complex), is extensively exposed, particularly in the southern part of the area.

The Placerita formation, the Rubio diorite, the Echo granite, and combinations of all three (San Gabriel complex) are believed to be of Early pre-Cambrian age. Rocks, much like these occur in many parts of southern California, and they are almost exactly like similar rocks quite certainly of Early pre-Cambrian age observed by the writer in many places in the United States, southeastern Canada, and northern Europe.

Next in order of age is anorthosite, which is unknown in other parts of southern California. This occurrence, like nearly all important known anorthosite bodies in the world, is considered pre-Cambrian. Most of the anorthosite, with extensively developed diorite-gabbro facies, occupies an area 18 miles long and 8 miles wide. Near by on the northeast is a smaller body of the diorite-gabbro facies about 4 miles

long. This bluish-gray to white anorthosite, with its diorite-gabbro facies, plainly cuts and holds large and small xenoliths of the San Gabriel complex and sends dikes into the latter. It also holds xenoliths of earlier consolidated dioritic facies (Pl. 3, fig. 2). Since publication of the 1934 paper, the writer has seen a small outlying body of the anorthosite cutting the San Gabriel complex more than 8 miles southwest of the large area, in lower La Tuna Canyon in the western Verdugo Mountains. Still later several small bodies of what are believed to be mafic facies of the anorthosite were observed about 4 miles northwest of Valyermo. These are at the middle-northern boundary of the San Gabriel Mountains and about 14 miles east of the large area of anorthosite. These may be remnants of a former large eastern extension of the now-exposed main body of anorthosite cut out by a large batholith of Late Mesozoic granodiorite. At many places the main body of anorthosite is cut by granite and pegmatite dikes which are offshoots of the Late Mesozoic granodiorite. In the northwestern part of the large area, overlooking Soledad Canyon, such granitic dikes, both large and small, are unusually numerous. These medium-grained granite dikes are light gray to nearly white, and the medium-grained anorthosite which they cut is also nearly white. Some care must be exercised in distinguishing between these rocks. Oakeshott (1937, p. 227) ,who reported on this area after publication of the writer's geologic map (Miller, 1934), has failed to make the distinction. Instead of white anorthosite mapped as the principal country rock by the writer, Oakeshott's map shows both granite and white syenite. The fact is that numerous granitic dikes cut anorthosite. Evidently Oakeshott has mistaken anorthosite for both granite and syenite.

Certain fine- to medium-grained diorite dikes, which cut the anorthosite at various places, probably represent late magmatic differentiates of the anorthosite. Their contacts are sharp or fairly sharp, and they are usually 1–3 feet in width. They are cut by the Wilson diorite, and by dikes from the Lowe granodiorite of Late Mesozoic age.

Late Mesozoic intrusives.—In the western and middle-southern San Gabriel Mountains, all formations above mentioned are cut sharply by the Wilson diorite, a medium-grained, massive to very moderately foliated quartz diorite. It occurs mainly as large and small, crudely defined, sill-like bodies cutting the San Gabriel complex. It is probably of Late Mesozoic age. Chemical analysis, norm, and mode of a specimen from the type locality are given in Table 2 (No. 1).

The Lowe granodiorite, varying to quartz monozonite, is extensively exposed in various large and small areas of the western San Gabriel Mountains. It usually exhibits a moderate degree of primary foliation. A common facies is light gray with large phenocrysts of pink potash feldspar. The Lowe granodiorite cuts all above described formations, with sharp contacts. Like the Sierra Nevada batholith of granodiorite, it is without much doubt of Late Jurassic or Early Cretaceous age. Chemical analysis, norm, and mode of a specimen are given in Table 2 (No. 3).

Numerous aplite, granite, pegmatite, and silexite dikes, representing offshoots of the Lowe granodiorite, cut all older formations sharply.

Tertiary dikes and volcanics.—Three kinds of dikes sharply cut various pre-Tertiary formations. They are probably not very different in age, and most likely Middle

Tertiary. One kind has been called porphyrite in the writer's 1934 paper. It might, however, be better to call them quartz latite porphyry dikes in view of the fact that, after careful restudy, several thin sections quite certainly show considerable potash feldspar in the very fine-grained, light-greenish-gray groundmass. The groundmass in the other sections is either too fine-grained or too badly altered for positive determination. These dikes are widely distributed in the southern part of the writer's 1934 map area.

Scores of lamprophyre (or gabbro-diorite) dikes occur in the northwestern border portion of the San Gabriel Mountains. They cut sharply not only the Parker diorite but also the aplite dikes in it. Possibly the aplite and lamprophyre dikes are complementary, but the latter may be earlier Tertiary.

Sharply defined diabase (or basaltic) dikes are widely distributed in the western San Gabriel Mountains. They are definitely younger than the quartz latite porphyry dikes and they are almost certainly correlative of similar dikes of Middle Miocene age in the Santa Monica Mountains. The writer has recently discussed the secondarily developed foliation in many of these dikes (1945, p. 182–185, 188–190).

Miocene volcanic rocks—both lavas and pyroclastics—occur along parts of the borders of the western and middle-southern San Gabriel Mountains, but the principal areas are in the middle-northern part as shown on the writer's 1934 geologic map.

SAN GABRIEL MOUNTAINS (EASTERN)

Introduction.—Most of the eastern part of the San Gabriel Mountains has not been mapped geologically. Several important formations, comprising the northeastern border portion, including the San Andreas fault zone, are represented on the State Geologic Map of 1938. A small-scale geologic map of the eastern border portion published by Noble (1932a, Pl. 3) shows three important divisions of the crystalline rocks. Observations by the writer have been made in many parts of the eastern San Gabriel Mountains. Some of these will here be recorded for the first time.

Pre-Cambrian rocks.—Oldest of these rocks are metasediments which are essentially like the Placerita formation of the western part of the mountains, and they are quite certainly correlative with that formation. The metasediments are nearly everywhere so intimately associated with intrusives of the San Gabriel complex that satisfactory mapping of separate areas would seldom if ever be feasible. Among other places where the well-bedded metasediments, including quartzite, schist, and crystalline limestone, may be seen is Lytle Canyon between its mouth and Glenn Ranch (Pl. 2, fig. 1).

Both Rubio diorite (and metadiorite) and Echo granite are widespread and nearly everywhere intimately associated in the San Gabriel complex.

As already suggested, the San Gabriel complex is extensively developed in the eastern San Gabriel Mountains. As usual it is an intimate mixture of Placerita metasediment, Rubio diorite (and metadiorite), and Echo granite in varying amounts. A belt of the typical complex, from less than a mile to several miles in width, extends many miles just north of the San Andreas fault from near Cajon Canyon to beyond Little Rock. Several miles of the southeastern part of this belt contains an unusual

amount of crystalline limestone. The complex is extensively exposed in a belt several miles wide extending across the southern part of the mountains from lower Lytle Canyon to west of lower San Antonio Canyon. Excellent exposures occur in Lytle Canyon from its mouth 4 miles up. These exposures illustrate all sorts of mixtures of Placerita metasediments, Rubio diorite and metadiorite, and Echo granite. These mixtures are largely migmatites, but remnants of the just-mentioned units are often clearly recognizable.

The complex is also extensively exposed in the southern part of the Rock Creek quadrangle and in the southwestern part of the San Antonio quadrangle.

Anorthosite has not been observed by the writer in the eastern San Gabriel Mountains.

An important formation, not seen in the western San Gabriel Mountains, is the Pelona schist, so named from the Sierra Pelona region just northwest of the mountains. It is a metasedimentary formation consisting very largely of mica schist with varying amounts of interbedded quartzite and some crystalline limestone. Unlike the San Gabriel formation, it is not cut intimately, or *lit-per-lit* injected, by granitic material. It is certainly of pre-Cambrian age, but younger than the San Gabriel complex. Practically all the Pelona schist in the eastern San Gabriel Mountains occurs in a northwesterly trending belt about 25 miles long and 2 to 5 miles wide. This belt, extending from lower Cajon Canyon almost to Valyermo, lies adjacent to the San Andreas fault on its south side. For 16 miles it is separated sharply by the great fault from the previously mentioned belt of the San Gabriel complex.

Paleozoic? strata.—Crystalline limestone, quite certainly much younger than that of the Placerita formation, occurs at a number of localities. Such well-bedded, bluish-gray to white, fine-grained, moderately metamorphosed limestone forms the southern part of the large hill 1 to 2 miles northwest to northeast of Valyermo at the middle-northern border of the mountains. This limestone is not intimately cut by granitic material, but, on the east, it is cut sharply by massive diorite which is regarded as Wilson diorite. Again, this limestone looks exactly like the Late Paleozoic (Mississippian?) limestone containing fossils in the vicinity of Victorville, and in the northern and northwestern parts of the San Bernardino Mountains as described beyond. Limestone, also presumably of Late Paleozoic age, occurs at two localities in the northern part of the Cucamonga quadrangle. One of these, according to Woodford (1943, p. 336), is in Cascade Canyon, and the other, seen by the writer, is fine-grained, moderately metamorphosed limestone on Cucamonga Peak.

Late Mesozoic intrusives.—What is regarded as Wilson diorite has been seen at a number of places in the eastern part of the mountains, but it is probably much less extensive than in the western part. Good exposures, presumed to be Wilson diorite, occur in upper San Antonio Canyon for 2 miles above Camp Baldy, on Big Rock Creek 3 miles northwest of Valyermo, and 2 miles northeast of Valyermo. There are probably other occurrences.

Lowe granodiorite is extensively exposed in the southwestern fourth of the Rock Creek quadrangle where it forms the eastern part of a fairly large batholith occupying the central portion of the San Gabriel Mountains. A body of the granodiorite several miles long cuts the Pelona schist at the eastern tip of the San Gabriel Mountains.

There are probably other occurrences. Some aplitic and granitic dikes, representing offshoots of the granodiorite, also occur.

Tertiary dikes and volcanics.—The dikes include both quartz latite porphyry and diabase (or basalt) similar to those of the western part of the mountains, but they seem to be less common. By the road about a mile below the summit in upper San Antonio Canyon, several quartz latite porphyry dikes cutting Pelona schist are crosscut sharply by a basaltic dike. One of the porphyry dikes cuts banded gneiss of the San Gabriel complex near Camp Baldy, and another cuts Wilson? diorite near the top of Mt. San Antonio. Similar porphyry and basaltic dikes were seen on the small ridge overlooking Lytle Canyon southeast of Glenn Ranch. Others no doubt occur.

The only volcanics known to the writer in the eastern half of the San Gabriel Mountains occur in lower San Dimas Canyon and westward. They are basaltic and andesitic lavas and agglomerates.

SANTA MONICA MOUNTAINS

Introduction.—The crystalline rocks of the Santa Monica Mountains include slate, granodiorite, and volcanic and dike rocks. Cretaceous and Cenozoic sediments are also abundant. A geologic map accompanying a report by Kew (1924, Pl. I) includes part of the northern side of the western two-thirds of the mountains. The eastern third of the mountains has been geologically mapped by Hoots (1931, Pl. 16), and Soper (1938, Pl. I) has published a geologic map of an area in the central part.

Triassic? slate.—Oldest of the rocks is the Santa Monica slate (Hoots, 1931, p. 88–89) which occupies a relatively large area in the middle-eastern part of the mountains. The slate varies to phyllite, and still more locally to mica schist. Everywhere bedding and foliation are parallel. The most highly metamorphosed portions are along contacts with, or as xenoliths in, the quartz diorite (described beyond) which is definitely the younger. In a few such cases there has been a little injection of the schist *lit-par-lit* by granitic facies of the diorite. Hoots estimates the thickness of the formation as 5000–7000 feet, with neither top nor bottom exposed. No fossils have been found in it, but it is remarkably similar to the fossiliferous Triassic slate in the Santa Ana Mountains 45 miles distant.

Late Mesozoic intrusives.—A number of relatively large and small bodies of quartz diorite, varying to granodiorite locally, occur in the eastern Santa Monica Mountains. The two largest bodies lie north of Hollywood and West Hollywood. The rock is generally massive, but with more or less primary foliation, particularly near contacts with the slate. Both biotite and hornblende occur in the rock, the biotite usually in amounts ranging from 5 to 15 per cent. Often there are small basic schlieren. Locally small dikes of granite, aplite, and silexite cut the diorite. The diorite cuts the Santa Monica slate sharply, and it is overlain unconformably by Middle Miocene beds. It is, without doubt, to be classed with the rock mapped (Miller, 1934) as Wilson diorite in the San Rafael Hills only a few miles east of the easternmost areas in the Santa Monica Mountains.

Tertiary dikes and volcanics.—Hoots (1931, p. 101) mentions a few small trachyte dikes, probably of Miocene age.

Middle Miocene basaltic volcanic rocks—both lavas and pyroclastics—are very abundant and widespread, especially in the western two-thirds of the mountains where such volcanics, reaching thicknesses of several thousand feet, constitute about half the rocks.

Many large and small basaltic sills and dikes cut Middle Miocene beds sharply, but not the Late Miocene. Fine examples are shown on the geologic map by Hoots (1931).

According to Hoots (1931, p. 119) there are a few small Pliocene or younger basaltic intrusives.

SAN BERNARDINO MOUNTAINS

Introduction.—The San Bernardino Mountains are somewhat greater in area and higher than the San Gabriel Mountains. Altitudes of ridges and peaks throughout the mountains commonly range from 5000 feet to 11,485 feet, the latter being the greatest altitude in southern California. These mountains stand out boldly above the surrounding country, and they are topographically very rugged.

The eastern three-fifths of the San Bernardio Mountains has been mapped geologically by Vaughan (1922). A small section of the middle-northern border of the mountains has been mapped in detail by Woodford and Harriss (1928). A geologic map by Noble (1932a, Pl. 3) includes part of the western border of the mountains, but the data shown on the 1938 State map is the only information on the rest of the western part of the mountains.

Pre-Cambrian rocks.—The oldest rocks of the San Bernardino Mountains comprise an extensively developed complex of some metasediments and much diorite, metadiorite and/or amphibolite, all of which are more or less intimately cut to pieces, *lit-par-lit* injected, and locally assimilated by much granite and petmatitic granite. This complex is, in all important respects, like the San Gabriel complex of the San Gabriel Mountains, and the writer believes that it is the same in age and origin. It extends from one mountain range into the other practically without interruption.

The metasediments of the complex in the San Bernardino Mountains presumably belong in the category of the Placerita formation, the diorite (and metadiorite) is the same as the Rubio diorite, and the granite correlates with the Echo granite of the San Gabriel Mountains. These constituents of the complex vary greatly in amount, but the granitic material (often impure) generally predominates. Crude to excellent banding often characterizes the complex, such banding in places remarkably simulating bedding as, for example, along the road in Dry Morongo Canyon (Pl. 3, fig. 2) at the southeastern border of the mountains. Locally a quartz monzonite porphyry, with potash feldspar phenocrysts 1 to 2 inches in length, has resulted from assimilation of diorite by granite as well shown in lower Mountain Home Canyon and in Mill Creek Canyon 2 miles farther east. Porphyry just like it is of pre-Cambrian age in other parts of southern California as described beyond. Remnants of the metasediments seldom, and of the diorite more commonly, are recognizable as such. With sufficiently detailed field work, some of these remnants, as well as masses of the

FIGURE 1. STEEP-DIPPING, GRANITE-INJECTED PLACERITA METASEDIMENTS
Well-bedded marble, quartzite, and mica schist are included. Lower Lytle Canyon, eastern San Gabriel Mountains.

FIGURE 2. GRANITE-INJECTED RUBIO DIORITE
Strongly foliated metadiorite highly injected *lit-par-lit* by pegmatitic granite with resultant very straight banding. Dry Morongo Canyon at the southeastern border of the San Bernardino Mountains.

EARLY PRE-CAMBRIAN COMPLEXES

FIGURE 1. NEEDLES COMPLEX
Crystalline limestone (white) cut to pieces by syntectic monzonitic porphyry (dark). Southeast end of Bristol Mountains, near Amboy.

FIGURE 2. ANORTHOSITE
The nearly pure, white anorthosite contains more or less well-defined xenoliths of an earlier consolidated, dioritic facies of the anorthositic magma. Near Lang in Soledad Canyon, Los Angeles County.

granite, might be separately mapped as has been done in part in the western San Gabriel Mountains.

On Vaughan's map a large area and various small ones are mapped as "undifferentiated schists," and many large and small areas as "heterogeneous plutonic rocks." The writer has been in many parts of these areas, and he believes that the "schists" are very largely typical San Gabriel complex, and that the areas of "heterogeneous plutonics" are also largely San Gabriel complex in which the granitic material is more abundant than usual. Among other places where the San Gabriel complex is excellently shown within the "schist" areas is in Mill Creek Canyon in the vicinity of Forest Home (Aker's Camp) and along the road in Dry Morongo Canyon. The complex is well exhibited among other places, within the areas of heterogeneous plutonics, 2 to 4 miles northeast of Seven Oaks, in Mountain Home Canyon, and on each side of Potato Canyon. Considerable areas mapped as heterogeneous plutonics are in reality Late Mesozoic Cactus granite, as for example several square miles north of Seven Oaks, and southwest of Seven Oaks where the area mapped as Cactus granite is much too small.

The San Gabriel complex is also extensively exposed in the southwestern part of the San Bernardino Mountains. Most of the granite, gneiss, and schist (undifferentiated) shown on Noble's map (1932a, Pl. 3) belongs in this category. Excellent exposures, typical of the complex, occur along the road in Waterman Canyon, and along the road in the lower 3 miles of City Creek Canyon.

Vaughan (1922, p. 370, 372) mentions the occurrence of numerous lamprophyre dikes cutting granitic rocks in Rattlesnake Canyon. They are probably Early pre-Cambrian but they may be much younger.

The only Late pre-Cambrian Pelona schist known to the writer in the San Bernardino Mountains occurs along their southwestern border (Noble, 1932a, Pl. 3). These areas are all on the south side of the San Andreas fault, and they represent an eastward extension of the formation from the San Gabriel Mountains. The schist contains some beds of quartzite and limestone. Good exposures may be studied along and near the main highway in lower Cajon Canyon.

Paleozoic metasediments.—Formations definitely known to be of Paleozoic age occur in several parts of the San Bernardino Mountains. The principal areas, shown on Vaughan's map (1922), are in the middle-northern part of the mountains. They include three formations with a total minimum thickness of 10,000 feet. These are Arrastre quartzite, Furnace limestone, and Saragossa quartzite, which, with no known fossils at the time of his study, Vaughan (1922, p. 361–363) tentatively assigned to ages ranging from Early Cambrian to Silurian or Devonian. Woodford and Harriss (1928, p. 270) found Late Paleozoic (Mississippian?) fossils in the Furnace limestone, which makes the overlying Saragossa quartzite at least somewhat younger, possibly Pennsylvanian.

According to Vaughan (1922, p. 353) the Arrastre quartzite lies conformably under the Furnace limestone. If so, it must be much younger than Cambrian, probably about Middle Paleozoic. Vaughan says (p. 353) that the Arrastre quartzite is intimately associated with considerable granitic and pegmatitic material the source of

which was the Cactus granite magma. The steep-dipping, thin-bedded quartzite, in the form of a roof pendant, would have been easily subject to considerable penetration by pegmatitic granite magma. Because the Arrastre quartzite is closely involved with so much granitic material, it might be better to call the combination the Arrastre complex.

In the western San Bernardino Mountains, Noble (1932b, p. 356) has found Carboniferous crinoid stems in limestone in the eastern face of Ord Mountain about 6 miles southeast of Hesperia. Also according to Noble (1932a, p. 12) Paleozoic limestone occurs along the north side of the San Andreas fault north of San Bernardino.

Late Mesozoic intrusives.—Little if any Late Mesozoic Wilson diorite is positively known to the writer in the San Bernardino Mountains. For 6 or 7 miles along the "Rim of the World" highway, southwest to southeast of Lake Arrowhead, the Cactus granite contains large and small xenoliths of diorite which may be reasonably interpreted as Wilson diorite. Some Wilson? diorite, cut by aplite dikes from the Cactus granite, occurs on Cushenberry grade between Cactus Flat and Monarch Flat on the northern side of the mountains.

The Cactus granite, so named by Vaughan (1922, p. 365), occurs in many large and small masses throughout most of the mountains. It is very generally a medium-grained, light-gray, massive, biotitic granite varying to quartz monzonite. Locally it becomes distinctly porphyritic and variably gneissoid, the latter facies probably representing somewhat earlier consolidated, slightly more basic, border portions of the intruding magma (Pl. 7, fig. 2). Like the Lowe granodiorite (or quartz monzonite) of the San Gabriel Mountains, the Cactus granite usually cuts all previously mentioned formations sharply, but locally the country rock shows some indications of having been granitized or injected by it.

Woodford and Harriss (1928, p. 271–274) have described the Cactus granite of a small area in the middle-northern border of the mountains. Chemical analysis, norm, and mode of a specimen of the rock from its type locality at Cactus Flat are given in Table 2 (No. 16). This rock is a quartz monzonite. Vaughan's map (1922) of the eastern San Bernardino Mountains shows many small to fairly large areas of the Cactus granite which he so named (p. 365). As already stated, the writer is sure that considerable parts of Vaughan's "heterogeneous plutonic rocks" are Cactus granite. In his description of "Granites," Vaughan (1922, p. 364–374) favors the idea of at least two important "periods of intrusion," but the Cactus granite is not separately discussed as such. In other words, his descriptions of older and younger granites are interspersed often with no certainty as to which is which, and with only a hint (p. 352) that any of the granite may be pre-Cambrian. After many years of experience involving this problem in southern California, the writer realizes the difficulty of always distinguishing between a Late Mesozoic granite and an Early pre-Cambrian granite, but in most of the regions such a distinction can be made.

The Cactus granite is also extensive in the western San Bernardino Mountains. Field notes by the writer show that this granite, varying to quartz monzonite, occupies most of the northern part of the Redlands quadrangle. It is excellently exposed along the "Rim of the World" highway all the way from near the head of Waterman

Canyon to Big Bear Lake, in the vicinity of Lake Arrowhead, along the road to Green Valley, and for miles down City Creek road to City Creek Canyon. Noble's map (1932a, Pl. 3) shows two important areas still farther west in the mountains.

Late Cenozoic basalt.—Various small remnants of formerly much more extensive basaltic lava flows are described and mapped by Vaughan (1922, p. 380–384) as of Late Cenozoic age, probably Early Pleistocene.

LITTLE SAN BERNARDINO MOUNTAINS

Introduction.—The Little San Bernardino Mountains, 45 miles long and 7 to 9 miles wide, comprise a desert range with a northwesterly trend. The very rugged mountains, with altitudes commonly ranging from 3000 to more than 5000 feet, rise boldly thousands of feet above the Coachella Valley. The writer has made many observations on the rocks of these mountains, the southeastern part of which has been geologically mapped (Miller, 1944a, Pl. 2).

Pre-Cambrian rocks.—These mountains consist very largely of an ancient complex of igneous and metamorphic rocks in all important respects like common facies of the San Gabriel complex. In fact, this complex extends for about 140 miles, as a wide belt with little interruption, across the southern parts of the San Gabriel and San Bernardino mountains and throughout the Little San Bernardino Mountains. In the Little San Bernardino Mountains, the principal constituents of the complex are intimately associated diorite and metadiorite (or amphibolite) and gray to pinkish-gray, medium to moderately coarse-grained granite. There seems to be little or no definitely recognizable metasedimentary material involved. Here and there in the mountains, masses of the comparatively pure hornblende-rich diorite and pinkish-gray granite and pegmatitic granite may be seen, some of them probably large enough to be mapped separately. Chemical analysis, norm, and mode of a nearly pure specimen of the granite are given (Table 1, No. 11). It is here proposed to call this rock Berdoo granite from its occurrence in Berdoo Canyon. The diorite and the granite are very probably correlatives of the Rubio diorite and the Echo granite, respectively, of the San Gabriel Mountains.

Among many places where the complex is excellently exposed are Berdoo, Wide, and Dry Morongo canyons, where the more or less crudely foliated granite cuts to pieces the diorite and metadiorite very irregularly, the diorite being large and small inclusions. Some small dikes of granite and pegmatitic granite cut the diorite irregularly. Locally, granitic material injects the metadiorite *lit-par-lit*, producing crude to excellent banding (Pl. 2, fig. 2). In some places the banded complex is contorted. Most of the granite is variably contaminated with absorbed or assimilated dioritic material distributed parallel to the primary foliation of the granite. The granitic material usually predominates.

Mesozoic or Late Paleozoic diorite.—The state map of 1938 shows large areas of Late Jurassic? granite in the western and southeastern parts of the mountains, but this is not correct. However, a fairly large body of Mesozoic or Late Paleozoic quartz diorite sharply cuts the complex in the southeastern part of the mountains. This diorite has been called Fargo Canyon diorite by the writer (Miller, 1944a, p. 59). Chemical analysis, norm, and mode of this diorite are given in Table 2 (No. 15).

Late Mesozoic quartz monzonite.—Some massive quartz monzonite cuts both the complex and the Fargo Canyon diorite in the southeastern part of the mountains. This monzonite is no doubt the same as the writer's White Tank quartz monzonite of the Twenty-nine Palms region (Miller, 1938, p. 438–443). There may be other occurrences of the diorite and the monzonite not seen by the writer. Not far east of the Little San Bernardino Mountains there are extensive areas of the quartz monzonite.

SAN JACINTO MOUNTAINS

Introduction.—The San Jacinto Mountains rise very boldly thousands of feet above the surrounding country in the form of a single mountain mass culminating in San Jacinto Peak (altitude 10,805 feet). Most impressive is the eastern face where the vertical range in altitude between Palm Springs (altitude 455 feet) and the summit is 10,350 feet within a distance of only 8 miles.

A geologic report on the San Jacinto quadrangle, including the San Jacinto Mountains, has been published by Fraser (1931). In view of this fact, only a brief summary of the crystalline rocks will be given with comments on Fraser's findings by the writer, who has visited many parts of the quadrangle.

Paleozoic and/or Mesozoic complex.—According to Fraser (1931, p. 504–508) the oldest mappable unit of the quadrangle is a "metamorphic series," at least several thousand feet thick, consisting of "crystalline limestone, quartzite, biotite-feldspathic schist, hornblende schist, mica schist, injected schists and well-banded granitic gneisses." Recently the writer (Miller, 1948a, p. 21–25) has called this "series" the Palm Canyon complex consisting very largely of metasediments which are, in many places intimately cut and locally injected with dioritic, granitic, pegmatitic, and silexitic material. This complex, in the San Jacinto quadrangle, occurs in large and small areas mostly around the lower flanks of the San Jacinto Mountains, but one large mass extends up the southeastern flank to an altitude of 8500 feet. For reasons given beyond, the metasediments of this complex are probably Late Paleozoic. The areas mapped as "metamorphic series" by Fraser in the southwestern part of the San Jacinto quadrangle may or may not belong with the Palm Canyon complex, as pointed out in the following discussion of the Riverside-Elsinore-Coahuila area.

Mesozoic or Late Paleozoic granodiorite.—According to Fraser a plutonic series younger than the Palm Canyon complex comprises, in order of age, gabbro (p. 508) granite gneiss (p. 509, 529–533), and granite (p. 510, 525–529). He maps only one small area of gneissoid gabbro. The writer has found some massive to gneissoid gabbro-diorite and diorite cutting the Palm Canyon complex sharply in the area north of San Jacinto. The diorite and gabbro just described are believed to represent more basic massive facies of the writer's Bradley granodiorite (Miller, 1944a, p. 52–59) of Mesozoic, or possibly Late Paleozoic, age so well shown in the mountain spurs southwest, south, and southeast of Indio Mountain in the Indio quadrangle.

According to Fraser his "granite gneiss" is a marginal phase of his Late Mesozoic San Jacinto granite batholith and found only along the eastern base of the mountains.

After careful study the writer (1944a, p. 52–59) concluded that (1) it is more or less well-foliated granodiorite varying to quartz diorite and to quartz monzonite and not a granite, and (2) it is at least somewhat older than the more acidic facies of the San Jacinto batholith, possibly representing an earlier-consolidated facies of the general batholithic magma, but it may be as old as Late Paleozoic.

Along the main highway in the southeastern corner of the San Jacinto quadrangle and for 2 miles into the Indio quadrangle, there are excellent exposures of gray, medium-grained, massive to slightly gneissoid quartz diorite with small basic schlieren and with some orthoclase. Chemical analysis, norm, and mode of this diorite are given in Table 2 (No. 12). On the south side of Pinyon Flat, in the Indio quadrangle, this diorite cuts a metasedimentary-plutonic complex. On the same highway east and northeast of Pinyon Flat, similar but somewhat more gneissoid diorite outcrops for 4 miles. The diorite along this highway is like the Wilson orthoclase-bearing quartz diorite of the San Gabriel Mountains and quite surely belongs with the more massive facies of the Bradley granodiorite of the Palm Springs-Indo area (Miller, 1944a, p. 52–59).

Late Mesozoic batholith.—Fraser's San Jacinto batholith comprises a plutonic series ranging from quartz diorite through granodiorite and quartz monzonite to granite and pegmatite. The quartz diorite, which is the most common facies, is massive to moderately gneissoid, and it often contains basic inclusions or schlieren. The batholithic rocks are very extensive, constituting the main body of the San Jacinto Mountains. They cut all previously mentioned rocks and they are believed to be of Late Mesozoic age. Chemical analysis, norm, and mode of a specimen of the granodiorite (or quartz diorite containing some orthoclase) from Chino Canyon, northwest of Palm Springs, are given in Table 2 (No. 27). It is in all respects very similar to the La Posta quartz diorite of San Diego County and it is probably correlative with it. If so, it is a young member of the Late Mesozoic plutonic series.

JURUPA MOUNTAINS

Introduction.—This area includes a group of hills and low mountains northwest of Riverside. It is of particular interest because of the famous mineral locality at Crestmore about which much has been written. No published geologic map of the whole area is known to the writer, but the rocks of the Crestmore quarries have been described by Eakle (1917, p. 328–331), Daly (1935, p. 639–648), Woodford, Crippen, and Garner (1941, p. 352–360). Woodford (1943, p. 336–344) repeats the 1941 description.

Paleozoic? metasediments.—Daly (1935, p. 639, 642) states that the "oldest rocks of the Jurupa Mountains form a thick series of recrystallized sedimentaries for which the name Jurupa series is proposed." The stratigraphically lower part of the series, according to Daly, consists of quartzites, quartzitic schists, interbedded quartzite and schist, biotite gneiss and schist, with some crystalline limestone lenses. This part of the series he calls the "Undifferentiated complex" which has a thickness of several thousand feet. "Granodiorite cuts off the base of the section and intrudes parts of it" (Daly, 1935, p. 642). Daly (p. 642) says that the metasediments, mainly

the crystalline limestone quarried for cement manufacture, lies "on the complex with the same attitude and possibly conformably." Two divisions of these rocks, at the Crestmore quarries, have been called Chino Quarry (or Chino) limestone and Sky Blue Quarry (or Sky Blue) limestone; the two being at least 1000 feet thick. These are white, well-bedded, medium to fairly coarse-grained, and usually graphitic. These limestone divisions are separated by a relatively thin quartzite and quartz-biotite schist member. The crystalline limestone of the large hill near Colton, 3 miles northeast of Crestmore, quite surely belongs with the Crestmore limestone. The writer agrees with Woodford, Crippen, and Garner (1941, p. 353) in assigning a probable Late Paleozoic age to these limestones.

Field notes by the writer show that the old limestone quarry 4 miles northwest of Riverside, west of the big Riverside "granite" quarry, shows a great exposure of steep-dipping, coarse-grained, crystalline limestone with some interbedded quartzite, quartz-biotite schist with graphite flakes, and some quartzite *lit-par-lit* injected with pegmatitic and silexitic material. These rocks are cut irregularly by some diorite dikes, ranging to 15 feet in width and usually strongly foliated. All the rocks, including the foliated diorite, are cut by a network of small, massive, quartz diorite dikes which are doubtless offshoots of the Perris quartz diorite. The schists and quartzites associated with the Jurupa series are often variably injected *lit-par-lit* by granitic and pegmatitic material.

Late Mesozoic plutonics.—The igneous rocks of the Jurupa Mountains constitute a Late Mesozoic plutonic series similar to that of the Perris Block, but with the most basic member not present. Oldest of the series is quartz norite, which Daly (1935, p. 644) calls hypersthene-quartz diorite. It is probably the same as the Virginia quartz norite of the Perris Block. Next comes the Perris quartz diorite, which varies locally to granodiorite. It is the most widespread plutonic in the Jurupa Mountains. It is usually moderately gneissoid and it often has numerous lens-shaped basic inclusions or schlieren. A thin section of the darker-gray diorite from the Riverside "granite" quarry shows by volume percentages: andesine, 62, quartz, 18; biotite, 8; hornblende, 7; monoclinic pyroxene, 4; and a little each of magnetite, zircon, and apatite. A section of the lighter-gray diorite from the quarry shows: oligoclase, 60; quartz, 30; biotite, 8; and small amounts of magnetite, apatite, allanite, zircon, and sphene. Both rocks are medium-grained, granitoid, and allotriomorphic. Next in order of age according to Daly (1935, p. 645–647), are quartz monzonite porphyry, granite porphyry, and pegmatite dikes.

RIVERSIDE-ELSINORE-COAHUILA AREA (PERRIS BLOCK)

Introduction.—This quadrangular area is bounded on the northwest by Colton and Corona, and on the southeast by Coahuila and Murietta. Much of it comprises the so-called "Perris peneplain" above whose surface (altitude about 1500 feet) numerous more or less conspicuous monadnocks rise. Most of the area is also known as the "Perris Block" which forms a relatively depressed block between the San Jacinto and Elsinore faults.

With the exception of the representation on the state map of 1938, the only important published geologic report (with map) covering a considerable part of the Perris Block is by Dudley (1935). Osborn (1939) described the rocks of a small central portion of the area. On the state map of 1938, data on part of the area came from an unpublished map by Larsen (1935). Irving (1935) described and mapped the northwestern part of the area. The writer has many observations throughout the Perris block, and results of his work are included in the following discussions.

Pre-Cambrian? complex.—The rocks that are probably the oldest known in this area occur east of Riverside in the Box Springs Mountains and the small mountains just east of them. These mountains, except a Late Mesozoic granite stock cutting them in the northern part of the Box Springs Mountains, consist of a metadiorite-granite complex, for which the writer here proposes the name Box Springs complex. Dudley (1935, p. 501) maps these mountains as quartz diorite. This is certainly not correct. The granite of the complex is strongly, but variably, foliated, and fine-to coarse-grained. It contains both biotite and hornblende in varying amounts. Pegmatitic and porphyritic facies are common. Intimately associated with the predominating granitic material are numerous more or less well-defined bands, lenses, and shreds of metadiorite which are usually schistose, biotite-rich, and variably granitized. The basic shreds and bands vary in width from less than an inch to several feet. Contacts, especially of the small, strung-out, basic lenses and shreds, are often fady. The granitic material is often somewhat contaminated as a result of assimilation of basic material. There are also pegmatitic bands or lenses and moderately foliated aplitic sills. The various units, and their foliation, are roughly parallel, giving the whole complex a crudely banded appearance. The typical complex just described is excellently exposed in the very steep southwestern face of the Box Springs Mountains, which rise 1000 to 1200 feet. The complex dips 50°–70° into the mountainside so that the exposed thickness is there at least 1500 feet. Similar rocks have been seen in other parts of the mountains by the writer. In the northern part of the mountains, a granite stock nearly 2 miles across cuts the complex, and the Perris quartz diorite cuts it on the southwest. Both diorite and granite quite certainly belong with the Late Mesozoic plutonic series to be described. Because of its high-grade metamorphism, particularly of its basic bands, and its similarity to important facies of complexes more or less surely of Early pre-Cambrian age in southern California, the Box Springs complex is tentatively regarded as of Early pre-Cambrian age, but it may be much younger.

Paleozoic and/or Mesozoic complex.—A series of rather strongly metamorphosed sediments, with some associated metatuffs, often more or less injected *lit-par-lit* with granitic material, is prominently exposed in many large and small areas within the Perris Block northeast of a nearly straight line extending from southeast of Arlington to the southwestern corner of the San Jacinto quadrangle. The thickness of this series is not known, but it seems to be at least several thousand feet. Because of characteristics of its own, the writer here proposes to call this series the Diamond Valley complex on account of its excellent exposures in the ridge on the north side of Diamond Valley, east and southeast of Winchester. Most of the areas have been

studied by the writer, and some of them will now be described in sufficient detail to give a good idea of the nature of the complex.

In the northwestern part of the Perris Block, there are several areas of the metasediments, including quartzites, quartz-biotite schists, and some crystalline limestones, which have been variably granitized (or silicated) and often injected *lit-par-lit* by granitic material. Dudley (1935, p. 493) includes the "schists and gneisses" of this category with his Elsinore metamorphic series (described beyond), but they may be partly or wholly older and they probably belong with the Diamond Valley complex. The belt of metamorphics several miles in length, southeast of Arlington, has been studied carefully by Irving (1935) who says that these rocks are biotite-plagioclase, orthoclase-quartz schists and gneisses variably injected by granitic material, variably granitized quartzite, and some wollastonitized limestone. Some of the schist is very fine-grained, dull gray, very thin-banded, and little injected. Because of the presence of the altered limestone, the prevalence of granitization, and the generally high grade metamorphism, Irving thinks that this belt of metamorphics is different from, and distinctly older than, the Elsinore series. The writer has seen small dikes and sills of Late Mesozoic quartz diorite cutting the granitized schists and quartzites, thus indicating that the granitization occurred well before the entry of the Late Mesozoic plutonic series to be described.

The areas 6 to 8 miles northwest of Perris consist mainly of quartz-biotite schists, variably injected with granitic material, much like the schists just described from southeast of Arlington. Osborn (1939, p. 925) says that "small bodies of granitized schist occur in the (Late Mesozoic) intrusive and apophyses of the igneous rock protrude through the schist." Here again the granitization took place well before the emplacement of the Late Mesozoic plutonic series.

Schists similar to those just described are common in the area about 3 miles west and southwest of Perris, a good deal of it being the very fine-grained, dull-gray, very thin-banded, little-injected kind.

In the type area of the Diamond Valley complex, which is the ridge 4 miles in length east and southeast of Winchester, all important facies of the complex are well exposed. The more or less strongly developed foliation in these rocks is parallel to to the bedding. Dips are steep, and the general strike is northwesterly or across the ridge. The exposed thickness of the complex is not accurately known, but it is no less than some thousands of feet. The principal rock types are fine-grained, dull-gray, very thin-banded, little injected biotite-quartz schist; well-bedded, fine-grained, little injected biotitic quartzite; granitized and *lit-par-lit* injected biotite-quartz schist; crudely banded biotite-quartz-feldspar injection gneiss; very fine-grained, dull-gray metatuffs associated with fine-grained, dark-gray altered lavas or metatuffs; and some gray, wollastonitized limestone. The steep-dipping volcanics form a belt at least hundreds of feet thick across the ridge 2½ to 3½ miles southeast of Winchester. Similar rocks, no doubt representing the same horizon in the complex, show as a wide belt in the butte just north of Winchester. The wollastonitized limestone in the magnesite quarry 3½ miles a little south of east of Winchester has yielded a fossil coral of Mississippian age according to Webb (1939, p. 198-201) who says that "within 1 to 5 miles of the Winchester quarry there are numerous scattered outcrops

of limestone of similar type; it seems probable that they are correlations of the series in which the coral was found."

Various areas have been mapped as "metamorphic series" in the southwestern fourth of the San Jacinto quadrangle by Fraser and very briefly described by him (Fraser, 1931, p. 506). The rocks of these areas are mica schists, quartzites, and quartz-mica schists which are often variably injected *lit-par-lit* by granitic material. They show steep dips and a general northwesterly strike. These are almost exactly like the predominant rocks of the Diamond Valley complex in the type area and other areas already described. They are of the nature of roof pendants or xenoliths on or in light-gray quartz diorite. Neither metavolcanics nor altered limestones were seen by the writer, though possibly they do occur. A few items of special interest will be mentioned. Thus, in a road cut 2 miles south of Hemet there are fine-grained, dull-gray, thin-banded, muscovite-biotite-quartz schist in part somewhat injected *lit-par-lit* by granitic material; biotitic quartzite somewhat injected; and some biotitic quartz schist-granite injection gneiss. These are cut by dikes and sills of light-gray, massive quartz diorite. In Bautista Canyon, 3 miles from its mouth, a large body of metamorphic rocks, like those just described, is cut by light-gray, massive to somewhat gneissoid quartz diorite with some pegmatitic granite offshoots crudely injecting the previously metamorphosed and injected sediments near the contact. A similar relationship occurs in the vicinity of Sage. This quartz diorite is quite certainly the same as the La Posta quartz diorite of San Diego County. At the north end of Mica Butte, south of Hemet, pink, variably contaminated, gneissoid granite (older than the near-by quartz diorite) is intimately associated with fine-grained, gray quartz-biotite schist and similar schist much injected *lit-par-lit*. Contacts are not sharp, and evidently the granite magma injected and partially digested the schist.

From the above descriptions of the Diamond Valley complex, it seems clear that (1) the complex is at least in part of Mississippian age as proved by fossil evidence, and (2) that the original sediments—shales, sandstones, and limestones—were strongly and regionally metamorphosed and variably granite-injected before emplacement of the Late Mesozoic plutonic series which invaded them. As stated by Fraser (1931, p. 507), the metamorphics of the San Jacinto quadrangle, including those of the southwestern part, must be older than the Late Mesozoic San Jacinto batholith which intrudes them. "They must have been altered before the entrance of the magma into them directly, because now the degree of metamorphism of the schists near the contact is not noticeably more intense than it is some miles away. It therefore seems unlikely that the metamorphism was directly due to intrusion" of the Late Mesozoic batholith. Local intrusion and injection of the metasediments, near contacts, by granitic material from the Late Mesozoic intrusive series should not be confused with distinctly earlier granitic intrusion and injection.

The Diamond Valley complex is, in considerable part, like the already described Late Paleozoic? Jurupa series northwest of Riverside; it is much like the Julian schist (complex) believed to be of Triassic and Paleozoic? ages in San Diego County; and it is, in some respects, like the Palm Canyon complex (Miller, 1944a, p. 21–25) of the San Jacinto Mountains, but there are important differences.

The sediments of both the Elsinore series to be described and the Diamond Valley complex are generally and rather uniformly altered, but the degree of metamorphism of the former is moderate, with shales seldom changed beyond the phyllite stage, while a distinctly higher-grade metamorphism characterizes the latter. Also, the metasediments of the Diamond Valley complex, unlike those of the Elsinore series, are variably but rather generally granitized and injected *lit-par-lit* by granitic material older than the Late Mesozoic plutonic series. Mappable bodies of the older granite have not, however, been found by the writer. Both Elsinore and Diamond Valley metasediments show little more than very local evidence of greater metamorphism near contacts with the Late Mesozoic batholith than those distant from the contacts. Near contacts in both cases, however, there may be some injection by acidic, Late Mesozoic, batholithic material. In spite of the marked difference in degree of metamorphism, there is considerable reason for believing that the Diamond Valley complex and the Elsinore series are partly or wholly correlatives. These two sets of rocks are separated by a nearly straight narrow zone running through points 2 miles southeast of Arlington, 3 miles southwest of Perris, 5 miles south of Winchester, and across the southwestern corner of the San Jacinto quadrangle. Within this zone, south of Perris, and southwest and south of Winchester, slates and moderately metamorphosed quartzites of the Elsinore series seem to grade into mica schists, quartz-mica schists, and quartzites across the northwesterly strike of the beds. If so, the Diamond Valley complex is at least partly of the same age as the Triassic Elsinore series, and, like the latter, the transitional metasediments show little or no injection *lit-par-lit* by granitic material.

Fossil evidence shows that at least part of the Elsinore series is Triassic and that at least part of the Diamond Valley complex is Paleozoic (Mississippian). Therefore, the writer tentatively suggests that at least part of the Diamond Valley complex may be older than the Elsinore series and not merely a more highly metamorphosed facies of the Elsinore as interpreted by Dudley (1935, p. 493). However, both the Diamond Valley complex and the Elsinore series may be largely correlatives, ranging in age from Triassic to Mississippian and possibly even somewhat younger and older.

Triassic rocks.—The Elsinore metamorphic series, so named by Dudley (1935, p. 493), includes metasediments and metavolcanics very much like those of the neighboring Santa Ana Mountains and no doubt correlative with them, since they are of Triassic age. Most of the metasediments are dark-gray slates and phyllites, gray quartzites which lie mostly above the slates, and some cherts, all representing a generally uniform, low-grade metamorphism. According to Fairbanks (1893, p. 106) a lens of gray crystalline limestone, about 500 feet long, occurs in the slates 3 miles east of north of Elsinore. Near some contacts with the more acidic Late Mesozoic intrusives, the sediments have been a little injected with granitic material, but widespread injection *lit-par-lit* by such material prior to the Late Mesozoic intrusions, so characteristic of the Diamond Valley complex, is lacking. Good exposures of slates and phyllites may be seen just north of Elsinore, in Railroad Canyon, north of Alber Hill, and in Dawson Canyon. Beyond the limits of Dudley's map, the writer has seen several square miles of the gray slates and phyllitic slates in Los Alamos Valley and

French Valley northeast of Murrietta Hot Springs. Phyllitic slates and quartzites also were seen in Bell Mountain southwest of Winchester. Irving (1935) suggests a thickness of 11,000 feet for the metasediments. Moderately altered andesitic and dacitic volcanics, including lavas and some pyroclastics, are at least in part intercalated with the metasediments, as for example by the highway just north of Elsinore. For most part, however, the volcanics lie about the metasediments.

Dudley (1935, p. 497, 498) says that his Temescal dacite porphyry intrudes both slates and volcanics of his Elsinore series and that it is, in turn, cut by various members of the plutonic series next to be described. Irving (1935) is quite sure that the dacite porphyry of his area does not intrude the Elsinore series, but rests upon the latter. The writer has not checked this matter in the field. Dudley (1935, p. 499) thinks the porphyry is the oldest member of the Late Mesozoic plutonic series to be described (1) because it is not of abyssal origin, and (2) because it is much too acidic to represent the earliest member of the plutonic series.

Late Mesozoic plutonics.—The plutonic series constitutes the northwestern end of a great Late Mesozoic batholith which, to quote Larsen (1941, p. 442), "underlies a strip from 60 to 100 miles wide and 1000 miles long from near Riverside, California, to the southern tip of Lower California." Larsen's study of a strip across the northwestern part of the batholith, and 70 miles along its length, in southern California showed that it "is made up of many separate injections, and, for most part, early injections had become largely crystalline before succeeding magmas were intruded. The succession of intrusions was from gabbro to granite." The members of the plutonic series in the Perris Block are, in approximate order of age, Gavilian Peak gabbro (Osborn, 1939, p. 925), Virginia quartz norite (Dudley, 1935, p. 501, 502), Perris and Estelle quartz diorite (Dudley, 1935, p. 501) and Val Verde tonalite (Osborn, 1939, p. 926), Lakeview quartz diorite (Dudley, 1935, p. 502), Steele Valley granodiorite (Dudley, 1935, p. 502), Cajalco quartz monzonite (Dudley, 1935, p. 502), La Posta quartz diorite, granite (Osborn, 1939, p. 927), and aplite and pegmatite dikes.

The Perris quartz diorite is common and widespread, the largest area extending from south of Riverside to Perris. This diorite is massive to moderately gneissoid with some irregularly distributed basic inclusions or schlieren arranged roughly parallel to the foliation. Chemical analysis, norm, and mode of a specimen of the Perris quartz diorite taken 3½ miles east-southeast of Riverside are given in Table 2 (No. 13). The mode of a specimen from elsewhere is given by Dudley (1935, p. 501). A thin section of finer-grained granodiorite from a dike in the Perris quartz diorite by the road 4 miles northeast of Elsinore shows by volume percentages: quartz, 23; andesine, 40; microcline, 22; biotite, 8; hornblende, 6; and a little magnetite and sphene.

According to observations by the writer, most of the widely exposed plutonic rock exposed in the southwestern part of the San Jacinto quadrangle is light-gray, massive to moderately gneissoid, quartz diorite, with small euhedral biotites and hornblendes, almost exactly like the widely exposed La Posta quartz diorite of southeastern San Diego County (Miller, 1935, p. 129). Field work in 1945 convinced the writer that

this quartz diorite is the same as the La Posta quartz diorite of southeastern, central, and middle-northern San Diego County there regarded as next to the youngest member of the Late Mesozoic plutonic series.

SANTA ANA-ELSINORE MOUNTAINS

Introduction.—The Santa Ana Mountains, together with their southern extension called the Elsinore Mountains, form a northwesterly trending range with a maximum altitude of 5680 feet. The eastern front 1000 to 3000 feet high, bounded by the Elsinore fault, is very steep, while the downslope to the southwest is much longer and more gradual.

The only worth-while published geologic maps pertaining to this mountain range are the small-scale part of the state map of 1938 which leaves much of the area blank, and the northern end of the range forming part of a map in a report by English (1926, Pl. 1).

Triassic rocks.—A metasedimentary-metavolcanic series constitutes the oldest known rocks of the Santa Ana-Elsinore Mountains. It no doubt belongs, at least in part, with the Elsinore metamorphic series so named by Dudley (1935, p. 493). Mendenhall (1912, p. 505) described the series many years ago, stating that the moderately, but variably, metamorphosed sedimentary material is largely dark-gray slate of unknown thickness, and that metavolcanics (mainly andesites), also of unknown thickness, unconformably overlie the slate. In the large area of these metasediments west of Murrieta and Temecula, the writer has seen fine exposures of black slates, dark-gray quartzites, and some gray fine-grained arkose. The slate looks very much like that above described as occurring in the Santa Monica Mountains. In none of the localities studied by the writer are the metasediments injected *lit-par-lit* by granitic material. Fairbanks (1893, p. 115) reported fossiliferous limestone in black slate in Ladd Canyon, and he stated that the fossils indicated a Carboniferous age. Apparently these fossils were later determined by J. P. Smith (1904, p. 352) as Triassic, and still later, according to Mendenhall (1912, p. 505–506), some fossils from Bedford Canyon were pronounced Triassic by Stanton. According to these findings the Elsinore series of the Santa Ana Mountains is largely or wholly of Triassic age, with the possibility that some may be Paleozoic.

Field notes by the writer indicate extensive occurrence of the metavolcanics, associated with some black slates, in Main Street (or Gypsum) Canyon. In Coldwater Canyon, above Glen Ivy Springs, black slate with some associated quartzite and dacite porphyry are well shown. The volcanics, cut by Late Mesozoic quartz diorite, are well exposed near the foot of the highway grade just west of Lake Elsinore. Steep-dipping metavolcanics, with some interbedded, altered tuffs, occur on a grand scale for about 2 miles along the same highway in San Juan Canyon just below the Orange County line. These are also regarded as Triassic, but no associated metasediments were seen by the writer. They are cut sharply by dikes of the Late Mesozoic quartz diorite.

Late Mesozoic plutonics.—Well exposed along the highway last mentioned, between the two areas of metavolcanics, a 6-mile-wide body of plutonic rocks cuts the metavolcanics on each side and holds some inclusions of them. The eastern half of these

FIGURE 1. PALEOZOIC STRATA AND ASSOCIATED ROCKS
Tilted Paleozoic strata, including Early Cambrian and forming the mountain on the right, rest unconformably upon the Early pre-Cambrian Needles complex of the gray foothills extending across the front of the range. Light-gray, Late Mesozoic quartz monzonite, forming the mountains in the left background, cuts the older rocks. Marble Mountains 5 to 7 miles north of Cadiz.

FIGURE 2. DETAILED VIEW OF MARIA FORMATION
Steep-dipping, alternating beds of dolomitic marble and quartzite. Northwestern Maria Mountains, 3¼ miles east of Cox Siding.

PALEOZOIC STRATA

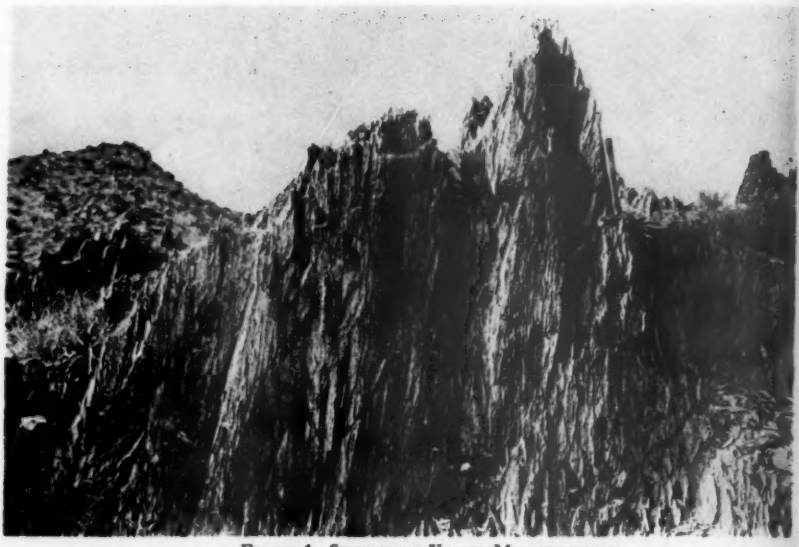

FIGURE 1. SIDEWINDER VALLEY METAVOLCANICS
Detailed view showing schistose metatuff with vertical dip. Twelve miles northeast of Victorville.

FIGURE 2. MCCOY MOUNTAINS FORMATION
McCoy Mountains metavolcanic-metasedimentary complex (dark) on the right is in contact with the Late Mesozoic Coxcomb granodiorite (light) on the left. Coxcomb Mountains 13–14 miles north-northeast of Desert Center.

LATE PALEOZOIC METAVOLCANICS

plutonics consists of a gray, medium-grained, generally massive to locally somewhat gneissoid quartz diorite with some irregularly distributed basic schlieren. A thin section shows by volume percentages: andesine, 62; quartz, 15; orthoclase, 8; biotite, 10; hornblende, 2; sericite (secondary), 2; magnetite, ½; and a little each of apatite, zircon, sphene, and epidote. This diorite is, in some places, cut by dikes of massive, light-gray granodiorite which also holds some small inclusions of the diorite. Contacts of inclusions against granodiorite vary from fairly sharp to indefinite. Locally, swarms of the inclusions are separated irregularly by networks of narrow dikes of finer-grained granodiorite with fady borders. It seems clear that the diorite represents a somewhat earlier solidified phase of the same batholithic magma which sent granodiorite dikes into the diorite with resultant slight digestion of the latter. The phenomena just described are finely exhibited in road cuts on the steep grade overlooking Lake Elsinore.

The western half of the body of plutonic rocks above mentioned is largely light-gray, medium-grained granodiorite. Chemical analysis, norm, and mode of a typical specimen from San Juan Canyon are given in Table 2 (No. 22). This granodiorite is the source of the dikes which cut the diorite farther east, and it also sends dikes into the metavolcanics in San Juan Canyon west of the Orange County line. In the vicinity of San Juan Hot Springs, in lower San Juan Canyon, a large body of massive quartz diorite, with small schlieren, comes against, and sends dikes into, the already mentioned metavolcanics on the east.

The writer believes that the quartz diorite and granodiorite occupy many square miles of the Santa Ana-Elsinore Mountains. As far northwest as Coldwater Canyon (above Glen Ivy Springs), similar diorite and granodiorite cut slates and metavolcanics of the Elsinore metamorphic series. As already indicated, the diorite and the granodiorite are of nearly the same age, probably Late Jurassic. They are certainly post-metavolcanic and pre-Upper Cretaceous; beds of the latter occur in the northwestern part of the mountains. The quartz diorite and the granodiorite are probably correlatives of the Alpine quartz diorite and Descanso (or Stonewall) granodiorite, respectively, in San Diego County.

Tertiary volcanics and sills.—The only other crystalline rocks in the Santa Ana-Elsinore mountains are Middle Tertiary volcanics and some sills which occur in a number of relatively small scattered areas.

SAN DIEGO COUNTY

Introduction.—Viewed broadly, most of San Diego County (area 4221 square miles) is a mountainous region forming part of the Peninsular Range. It represents an Early Quaternary, old-age surface which has, for the most part, been greatly rejuvenated, the uplift having been accompanied by much faulting on small and large scales (Miller, 1935b). The rejuvenated surface has also been considerably modified by stream erosion, leaving the surface in a general condition of late youth or early maturity in the normal cycle of erosion. The highest mountains, with altitudes reaching more than 6000 feet, form a wide belt extending northwesterly from the southeastern part of the county to the middle-northern part. From this belt of highest mountains there is a general downslope to the southwest to a coastal belt 6

to 12 miles wide which ranges from sea level to about 450 feet. The eastern side of the belt of highest mountains, except in the north, is marked by the high, steep Elsinore fault scarp facing the generally much lower desert region of the eastern part of the county.

Most of San Diego County consists of crystalline rocks. The state geologic map of 1938 gives the best general idea of the kinds and distribution of several important crystalline rock formations, but, because of lack of data, nearly half the area of the county is left blank. On the state map, data for the northwestern part of the county (San Luis Rey quadrangle) came from an unpublished map by Larsen (1935), and for the middle-western, middle-northern, and northeastern parts from unpublished maps by Eckis (1931). Mention should be made of the pioneer work of Fairbanks (1893, p. 76–92) who published field notes taken on a geologic reconnaissance of part of the Peninsular Range of southern California, including San Diego County. Ellis and Lee (1919, p. 1–76) briefly discussed the crystalline rocks of the county and presented a highly generalized geologic map.

Published reports, accompanied by detailed geologic maps, on the crystalline rocks of the county are few and rather limited. Important among these are a paper on the central part of the county by Hudson (1922, p. 181–212), one on the same area by Donnelly (1934, p. 337–348), and one by the writer (Miller, 1935a, p. 115–141) on a strip across the southern part of the county. Some crystalline rocks in the La Jolla quadrangle are described and mapped by Hanna (1926, p. 199–204; 220–227). Based upon Larsen's work, Hurlbut (1935, p. 619) published a map of part of the quadrangle showing the distribution of the Bonsall tonalite, and F. S. Miller (1937, p. 1401) published a map showing the distribution of the San Marcos gabbro in the whole quadrangle. Merriam (1941, p. 365–371) briefly discussed and mapped the middle-southern part of the Ramona quadrangle. The three papers last mentioned give only very brief statements in regard to general relationships of the crystalline rocks of northwestern San Diego County.

Many of the following statements in regard to the rocks of central and middle-northern San Diego County are based upon field work by the writer, some as late as 1945.

Paleozoic and/or Mesozoic complexes.—The Julian schist (complex) comprises the oldest known rocks in San Diego County. It was called the "Julian Group" by Merrill (1914, p. 12), the "Julian Schist Series, by Hudson (1922, p. 182), and "Julian Schist" by Donnelly (1934, p. 337). Still earlier it was recognized and described briefly by Goodyear (1888a, p. 517) and Fairbanks (1893, p. 82, 87). It is a rather complex lot of rocks, mainly metasedimentary with varying amounts of intimately associated igneous rocks. The most extensive known areas are in central, middle-northern, and southeastern San Diego County, with only a few small areas in the northwestern part. The complex, in its type region in the vicinity of Julian, has been described in detail by Hudson (1922, p. 182–190) and more briefly by Donnelly (1934, p. 337–340). Some occurrences in the southern part of the county have been described briefly by the writer (Miller, 1935a, p. 120–121). The main constituents of the Julian schist are fine-grained, gray to bluish-gray, fissile, quartz-muscovite-biotite schists; quartzites which are variably impure with biotite and muscovite;

phyllitic mica schists; various nonfissile, coarse-grained, quartz-biotite schists; and *lit-par-lit* injection gneisses. The igneous material of the injection gneisses consists of very thin layers of pegmatitic granite. Less common are layers of amphibolitic and actinolitic schists (both probably metavolcanic); sillimanite gneisses; and some beds of crystalline limestone. The full thickness of the complex is not known, but it is at least several thousand feet. In nearly all important respects the Julian schist (complex) is much like the Diamond Valley complex farther to the northwest in Riverside County. The two complexes are largely or wholly almost certainly of the same age, the writer having recently (1945) traced them within 8 or 10 miles of each other. Hudson (1922, p. 188–190) gives evidence suggesting that the Julian schist is either Triassic or Late Paleozoic, or both. The writer believes that most likely both ages are represented as is also probably true of the Diamond Valley complex. In any case the Julian schist is clearly older than the Late Mesozoic plutonic series.

Triassic? volcanics.—Probably next in age is a thick series of little-altered volcanic rocks found in various large and small areas along the western border of the crystalline rocks of San Diego County. Hanna (1926, p. 199–204), who called them Black Mountain volcanics, has described their occurrence in the La Jolla quadrangle, and he writer (1935a, p. 121–122) has described an area near La Mesa. They are mainly acites and andesites with some associated agglomerates and sediments. They are believed to be largely or wholly younger than the Julian schist and they are definitely older than, and intruded by, quartz diorite of the Late Mesozoic batholith. Hanna (1926, p. 204) says that they are probably Late Triassic or Jurassic.

Late Mesozoic plutonics.—The Late Mesozoic plutonic series of northwestern San Diego County (San Luis Rey quadrangle), according to F. S. Miller (1937, p. 1398–1399), shows an intrusive sequence including San Marcos gabbro, Green Valley tonalite, Bonsall tonalite, and Woodson granodiorite, the last-named being the most widespread. F. S. Miller (1937, p. 1399–1425) describes the San Marcos gabbro in detail, including discussion of six chemical analyses, norms, and modes of the rock. Hurlbut (1935, p. 609–630) discusses inclusions in the Bonsall tonalite and gives two chemical analyses, norms, and modes of the tonalite (p. 613).

In southern San Diego County, the Late Mesozoic plutonic sequence determined by the writer (Miller, 1935a, p. 123–132) is Viejas gabbro-diorite, Alpine quartz diorite, Harbison quartz diorite, Descanso granodiorite, La Posta quartz diorite, and Rattlesnake? granite. Both the La Posta and the Descanso are extensive. Chemical analyses, norms, and modes of specimens of the Viejas gabbro, Alpine quartz diorite, La Posta quartz diorite, and Descanso granodiorite are given in Table 2 (Nos. 5, 4, 6, 7). The Rattlesnake granite may occur in some areas of mixed rocks, as for example west and north of Jacumba, where true granite sharply crosscuts granite-injected Julian schist in a manner similar to that of the Rattlesnake granite described by Hudson (1922, p. 208).

The plutonic sequence in central San Diego County does not seem to be so definitely established. The writer tentatively suggests the following Late Mesozoic sequence: San Marcos gabbro (and Cuyamaca basic intrusive), Green Valley tonalite, Bonsall tonalite, Lakeview tonalite, Stonewall granodiorite, La Posta quartz diorite, and Rattlesnake granite. The writer, after field study, believes that the Santa Teresa

Valley area of Green Valley tonalite mapped by Merriam (1941, p. 365) is correlative with the Alpine quartz diorite of southern San Diego County (Miller, 1933a, p. 126).

In the Julian area, according to Hudson (1922, p. 192, 207), the post-Julian Stonewall granodiorite (or quartz diorite) is older than the Cuyamaca basic intrusive, but the evidence is not very convincing. For the Ramona area, Merriam (1941, p. 365–367), following Hudson, lists the Stonewall granodiorite (or quartz diorite) as pre-San Marcos and post-Julian, and he calls it Triassic? The writer thinks that these age assignments are doubtful. Thus on the grade southeast of Santa Ysabel, crudely foliated Stonewall granodiorite contains many small xenoliths of somewhat altered Cuyamaca basic intrusive. Where the Stonewall granodiorite and the basic intrusive come together near Cold Spring, south of Stonewall Peak, the former sends dikes into the latter. A large exposure on the north side of Cuyamaca Lake shows an intimate mixture of the granodiorite and basic intrusive, the former being the younger as plainly shown by pegmatitic granite dikes of the Stonewall cutting the basic rock. Large exposures in a field a little northeast of Cuyamaca Lake are quartz diorite (Alpine) holding small xenoliths of more basic rock (Cuyamaca or Viejas) and cut, and very locally migmatized, by some Stonewall granodiorite.

The Stonewall granodiorite and the Descanso granodiorite (Miller, 1935a, p. 127–128) are, in all important respects, much alike, and, in the field, they seem plainly to merge between the type regions at Descanso and Stonewall Peak, thus indicating their age equivalence. The Viejas gabbro-diorite of the Descanso region is the oldest member of the Late Mesozoic plutonic series, and it is quite certainly of essentially the same age as the Cuyamaca basic intrusive. The fact that the Descanso granodiorite is definitely younger than the Viejas gabbro-diorite points strongly to a similar age relationship for the Stonewall granodiorite, or at least much of what is mapped as such. On the basis of observations by the writer, it is suggested that what is mapped as Stonewall granodiorite (or quartz diorite) by both Hudson and Donnelly includes more than one member of the plutonic series. For example, west and southwest of Julian, in the vicinities of Wynola and Pine Hills, the writer has seen a large body of massive quartz diorite mapped with the Stonewall granodiorite by Hudson. It contains schlieren and xenoliths of variably granite-injected Julian schist. This diorite is just like the writer's Alpine quartz diorite (older than the Descanso granodiorite) in southern San Diego County. What is mapped as Stonewall granodiorite probably also includes distinctly older granitic material which could have injected the schist before intrusion of the Late Mesozoic plutonic series.

According to both Hudson and Merriam, the Julian schist was injected *lit-par-lit* by granitic material from the Stonewall granodiorite. Hudson (1922, p. 184, 186–187) says that the injection gneisses occur only near contacts with the granodiorite in the Julian region, but Donnelly (1934, p. 378) says that they occur also in many places in the interior of the main body of the schist. The writer's experience agrees with Donnelly's in middle-southern and southeastern San Diego County, where many large and small bodies of the schist have been variably injected *lit-par-lit* throughout. Here, as in the Diamond Valley complex, the Julian schist, or at least the older part of it, was probably injected *lit-par-lit* rather generally by older Mesozoic, or possibly Late Paleozoic, granitic material whose source body is now little if at all

recognizable, after which the schist, particularly border portions of it, was again variably injected, this time by pegmatitic granite from the Late Mesozoic Stonewall (or Descanso) granodiorite.

The writer has seen evidence in southern and central San Diego County that the Julian schist was injected *lit-par-lit* before the intrusion of the Late Mesozoic plutonic series, even early members of it, as along the road up Laguna Mountain, and in the small mountain 1 to 3 miles southeast of Buckman Springs. Again, the older quartz diorite (Alpine) member of the plutonic series northwest of Wynola contains more or less granite-injected xenoliths of the schist. There is also clear evidence that the Stonewall (or Descanso) granodiorite has cut to pieces and variably injected the Julian schist, as is well shown along the road between Julian and Banner. For about a mile eastward from Julian, the schist is very little injected, but it contains some small pegmatites. Then for several miles down the highway, to and beyond Banner, many excellent exposures show the steep-dipping Julian schist cut to pieces, and crudely and variably injected *lit-par-lit*, by the Stonewall granodiorite which sends some small pegmatite dikes into the mixture. By far most of the rock is granodioritic material. Some belts of the granodiorite contain only a few small xenoliths of the schist. Much of the rock is, however, crudely banded migmatite with granitic material predominant. The granodiorite varies from fairly massive to well foliated. It is mainly in the form of large and small sills which have cut, displaced, and partly absorbed schist material causing most of the granodiorite to be somewhat impure or contaminated.

Phenomena similar to those just described occur along the road for several miles southeastward from Julian; at many places along Sunrise highway between Laguna Mountain and Cuyamaca Lake; and at various other places in central and southeastern San Diego County.

The position of the La Posta quartz diorite in the Late Mesozoic plutonic series is a matter of importance. Reasons have been given (Miller, 1935a, p. 131) for regarding it as probably younger than the Descanso granodiorite. Field work by the writer in 1945 has shown not only that such an age relation is certain, but also that this quartz diorite, extensive in southeastern San Diego County, occurs widely in the middle-eastern and middle-northern parts of the county. Thus large areas of the typical rock (Miller, 1935a, p. 129–130) occur in the southeastern part of San Felipe Valley and in the mountains just east of the valley; between San Felipe Valley and Lake Henshaw; through Dodge Valley, Oakgrove Valley, Aguanga Valley, Radic Valley, and the mountains just east of those valleys; and still farther north in the southwestern part of the San Jacinto quadrangle. This light-gray, massive, medium-grained quartz diorite, with its characteristic euhedral biotites and hornblendes, intrudes not only the Descanso granodiorite, but also its correlative Stonewall granodiorite as just southeast of Lake Henshaw, and on the southeastern side of Dodge Valley. A big road cut in the hills of the southeastern part of San Felipe Valley shows small and large, sharply defined, steep-dipping, granite-injected Julian schist xenoliths in the La Posta quartz diorite. A similar relationship was observed in a road cut at the western end of Oakgrove Valley.

Pegmatite and silexite dikes, representing offshoots of the more acidic members of

the Late Mesozoic plutonic series are common, as for example in the area of mixed rocks northwest of Jacumba. Special mention should be made of the pegmatites which carry gem minerals, such as tourmalines and kunzite, in the northwestern part of the county, near Pala and Mesa Grande.

Cenozoic dikes and volcanics.—Only two small basic dikes of Cenozoic age are known to the writer in San Diego County. Both are probably of Middle or Late Tertiary age. One is a basaltic dike cutting Eocene beds 2¼ miles north of La Jolla, and the other is a diabase dike cutting granodiorite by the highway 1 mile southeast of Descanso.

The Jacumba volcanics (Miller, 1937a, p. 138–140) occur in a number of small areas in the southeastern corner of the county. They include olivine basalts and pyroclastics. They rest upon brown sands and gravels and they are Late Tertiary or Early Quaternary.

IMPERIAL COUNTY (SOUTHWESTERN)

Introduction.—The only important areas of crystalline rocks in Imperial County are in the southwestern, eastern, and middle northern parts; the rest of the county, particularly the Imperial Valley, is occupied by Quaternary alluvium and some Late Tertiary strata. Foothills of the Peninsular Range, which come into the southwestern part of the county, contain important masses of crystalline rocks in regard to which published statements are relatively meager.

Paleozoic? metasediments.—The oldest known rocks seem to be metasediments, consisting of crystalline limestones, mica schists, and quartzites, which the writer has seen covering at least 6 or 7 square miles of the eastern part of the Carrizo (or Coyote) Mountains. Fairbanks (1893, p. 89) says that crystalline limestone, schist, and quartzite form much of the north end of these mountains. Mendenhall (1910, p. 342–343) says that the core of these mountains consists of metamorphic rocks in which blue or gray crystalline limestone, with some associated graphitic schist, predominates. Fairbanks (1893, p. 90) considered these metasediments to be Carboniferous or older, basing his opinion upon some shells found in crystalline limestone float. The writer (Miller, 1935a, p. 120) has described a small body of metasediments, quite certainly belonging in the same category, as occurring along the highway about 2 miles northeast of Mountain Springs in the mountains south of the Coyote Mountains. This body contains mostly gray mica schist with some interbedded quartzite and crystalline limestone. It is cut *lit-par-lit* by some granitic material. The writer tentatively assigned it to the Julian schist, and, if this is correct, it strengthens the view that at least part of the Julian schist, particularly the limestone-rich part, is Paleozoic. Other occurrences of limestone, no doubt belonging in the same category, are mentioned by Sampson and Tucker (1942, p. 137–138). One of these is white crystalline limestone on the southwestern slope of the Coyote Mountains, and the other is bluish-gray crystalline limestone in the northern part of the Fish Creek Mountains.

Late Mesozoic plutonics.—The extreme southwestern corner of the county, comprising some 50 square miles, is very largely Late Mesozoic La Posta quartz diorite in part described and mapped by the writer (Miller, 1935a, p. 129–132, Pl. 2). This diorite contains some xenoliths of metadiorite and at least one xenolith of the above-

mentioned metasediments. According to Fairbanks (1893, p. 88) the southeastern part of the Fish Creek Mountains consists of rather massive granite. This granite is probably also Late Mesozoic.

Late Cenozoic volcanics.—Along the northeastern, eastern, and southeastern sides of the Coyote Mountains, volcanic rocks—both lava flows and pyroclastics—lie under, and are in part interbedded with, marine strata of Late Miocene or Pliocene age, as in Alverson Canyon.

Still younger volcanics outcrop in a narrow belt at the base of the main part of the Peninsular Range about 5 miles a little south of west of Coyote Well. These volcanics, resting upon moderately consolidated sands and gravels, are believed to be of Early Quaternary age (Miller, 1935a, p. 139–140). They doubtless belong with the Jacumba volcanics, having been downdropped along the Elsinore fault.

IMPERIAL COUNTY (NORTHERN AND EASTERN)

Introduction.—This desert region of low mountains, separated by wide alluviated valleys, lies east of the San Andreas fault. The exposed bedrock formations are nearly all crystalline. Published statements or maps in regard to these rocks are, except for one small area, meager or lacking; the small area was mapped by Henshaw (1942).

Pre-Cambrian rocks.—Reconnaissance work by the writer indicates that the Chocolate Mountains, extending as far southeastward as due east of Niland, consist very largely of a complex of metadiorite, hornblende-rich diorite, possibly some metasediments, crudely banded gneisses, and variably contaminated granitic material. This complex is very similar to the Chuckwalla complex (Miller, 1944a, p. 16–17) so extensively exposed in the Chuckwalla Mountains next to the north and rather confidently regarded as of Early pre-Cambrian age. A belt of similar rock occurs in the small mountains southeast of Midway Well.

The Cargo Muchacho Mountains, forming a small mountain group in the southeastern part of the county, have been geologically described and mapped by Henshaw (1942). According to Henshaw (1942, p. 153–157), the oldest rocks are two formations largely or wholly metasedimentary. One of these, called the Vitrefrax formation, consists mainly of white quartzite, sericite schist, and associated kyanite-bearing sericite schist and quartzite. The other, the Tumco formation, is described as a fine-grained arkosite with some interbedded hornblende schist possibly of tuffaceous origin. Henshaw says that they are probably pre-Mesozoic. Next in order of age, and probably Mesozoic, according to Henshaw (1942, p. 157–160) is a plutonic sequence including quartz diorite, quartz monzonite, biotite granite, and leucogranite. Little evidence is given indicating that the granites are younger than the diorite and monzonite, and, based upon a brief study of the area a dozen years ago, the writer believes that the evidence points to the greater age of the granites which are certainly younger than the Vitrefrax and Tumco formations. Both of the granites, probably of essentially the same age, are, as stated by Henshaw (1942, p. 160) "locally characterized by an alignment of minerals and a bedded appearance which are not found in the quartz monzonite and quartz diorite." Both granites have been variably granitized, injected *lit-par-lit*, and become contaminated with material of the older forma-

tions. The leucogranite has sent numerous pegmatite and aplite dikes into the country rocks. The writer tentatively regards the Vitrefrax and Tumco formations, and the granites, as Paleozoic or older (probably Early pre-Cambrian) and the quartz diorite and quartz monzonite as Late Mesozoic.

Late Mesozoic plutonics.—In addition to the already mentioned Late Mesozoic quartz diorite and quartz monzonite, the writer has seen two bodies of quartz monzonite sharply cutting the Early pre-Cambrian (Chuckwalla) complex in the Chocolate Mountains northeast and north of Niland. One of these covers an area of fully 25 square miles from the vicinity of Beal Well west and south to the foot of the mountains. This monzonite, which is light-gray, massive, medium- to moderately coarse-grained, and slightly porphyritic, is much like the White Tank quartz monzonite so extensively exposed to the north in middle-northern Riverside County (Miller, 1938, p. 438–444; 1944a, p. 61–63). It is regarded as of Late Mesozoic age.

Cenozoic dikes and volcanics.—Several quartz latite porphyry dikes of Middle Tertiary age cut the quartz monzonite sharply in the canyon southwest of Beal Well in the Chocolate Mountains. These steep-dipping dikes, each 10 to 15 feet in width, form a roughly parallel system. They are notably sheared parallel to their walls, probably because of nearness to the San Andreas fault. Several dikelike bodies, called andesite by Henshaw (1942, p. 161), in the Cargo Muchacho Mountains no doubt belong in the same category. Similar quartz latite porphyry dikes, though usually not sheared, occur in various parts of southeastern California, as for example in the Desert Center region (Miller, 1944a, p. 65–66).

Tertiary volcanic rocks (probably Late Miocene) occur in various large and small areas as indicated in a general way on the state geologic map of 1938. There is an additional area along the base of the Chocolate Mountains north of Frink. These rocks are largely andesitic lavas with associated pyroclastics. About 8 to 10 miles west-southwest of Palo Verde, the volcanics are associated with red conglomeratic sandstone much as in the vicinity of Needles (Miller, 1944a, p. 126–127).

According to Henshaw (1942, p. 161), remnants of olivine basalt cap several hills in the Cargo Muchacho Mountains. These are doubtless Late Tertiary or Early Quaternary. They are very similar to the lava caps in the southwestern corner of Imperial County and the southeastern corner of San Diego County (Miller, 1935a, p. 139–140).

The small volcanic domes, including Pumice Butte and Obsidian Butte, on the southeastern side of the Salton Sea, are of special interest because they are of Late Quaternary age. They have been described by Kelley and Soske (1936).

PALM SPRINGS-BLYTHE AREA

Introduction.—This strip of country extends from the eastern flank of the San Jacinto Mountains near Palm Springs eastward through the middle of Riverside County to the Colorado River in the vicinity of Blythe. The strip is 120 miles long, and it varies in width from a minimum of 7 miles, east of Shaver Summit, to a maximum of 22 miles, in the Desert Center section. Altitudes range from 150 feet below sea level to 4500 feet. Rugged desert mountains rise steeply 1000 to 3000 feet above wide, heavily alluviated valley floors. From the standpoint of kinds and ages of crystalline

FIGURE 1. PALM CANYON COMPLEX
Metasediments, including quartzite marble, and mica schist, variably injected *lit-par-lit* by impure granite and pegmatitic granite, and cut by a 5-foot wide sill of Late Mesozoic quartz monzonite. By the highway 7 miles northeast of Palm Springs.

FIGURE 2. PALM CANYON COMPLEX
Crudely banded, granite-injected metasediments. In Dead Indian Canyon 12 miles west-southwest of Indio.

PALEOZOIC AND/OR MESOZOIC COMPLEX

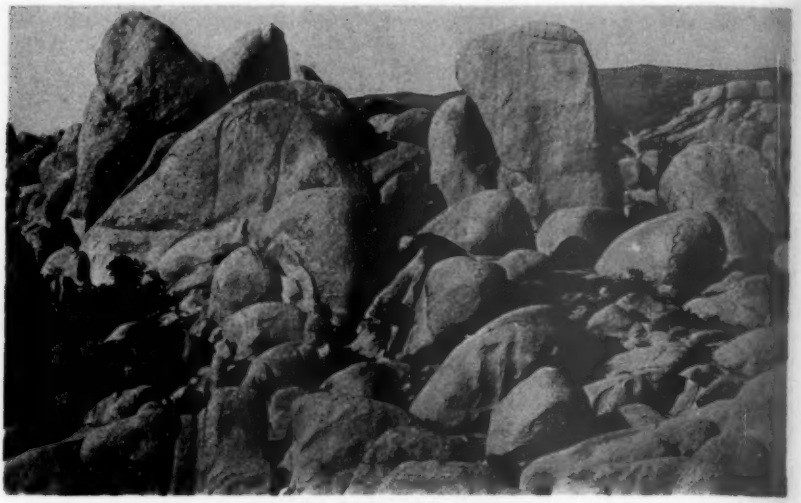

FIGURE 1. WHITE TANK QUARTZ MONZONITE
Typical outcrop of the usually massive quartz monzonite. At White Tank 10 miles south of Twenty-nine Palms.

FIGURE 2. CACTUS GRANITE
This granite here has a well-developed primary foliation dipping about 45°. At Cactus Flat in the middle-northern San Bernardino Mountains.

LATE MESOZOIC PLUTONICS

rock formations, this area is one of the most important in southern California. Since the writer has very recently published a rather detailed report (Miller, 1944a) on the geology of the area, accompanied by geologic maps, only a very brief summary is here presented.

Pre-Cambrian rocks.—The Early pre-Cambrian Chuckwalla complex comprises the oldest rocks of the area. It is a mixture of diorite and metadiorite, and a little still older metasediment, cut to pieces, injected, and migmatized or digested by granitic material. This complex is widely exposed in the Little San Bernardino Mountains, Cottonwood Mountains, Eagle Mountains, Chuckwalla Mountains, and Maria Mountains. It is here proposed to call the granite of the complex in the Little San Bernardino Mountains the Berdoo granite typically exposed in Berdoo Canyon. Chemical analysis, norm, and mode of this granite are shown in Table 1 (No. 11).

Next younger is the pre-Cambrian Orocopia schist consisting of metasediments, largely mica schist. It occurs in one large and several small areas in the general vicinity of Shaver Well.

Paleozoic metasediments.—One definitely known Paleozoic formation has been called the Maria formation from its occurrence in the Maria Mountains. It contains some poorly preserved crinoidal remains which may be as old as Middle Paleozoic. It consists of crystalline limestone, gypsum beds, quartzites, and schists with a total thickness of some thousands of feet (Pl. 4, fig. 2).

Metasediments with hematite ore, and probably of Paleozoic age, occur a few miles north-northwest of Eagle Mountain Camp. They mark the eastern end of the extensive "iron district" of the Eagle Mountains described by Harder (1912).

Paleozoic and/or Mesozoic complexes.—One Paleozoic or older metasedimentary-igneous complex has been mapped as the Palm Canyon complex. It is extensively exposed from south of Palm Springs southeastward for 12 or 14 miles. It consists largely of crystalline limestones, quartzites, and mica schists or phyllites in many places cut and locally injected with dioritic, granitic, pegmatitic, and silexitic material (Pl. 6, figs. 1, 2). It is highly deformed. The writer has found what may possibly be Paleozoic crinoidal remains in the limestone. However, some of the complex may be pre-Cambrian.

A formation called the Maria-plutonic complex occurs in the Maria Mountains. The igneous components are probably Paleozoic but may be Mesozoic. It contains crystalline dolomitic limestones, quartzites, and schists of the Maria formation cut by dioritic and granitic rocks, usually in the form of sills, and irregularly by many pegmatite dikes. The metasediments are much granitized and locally injected *lit-par-lit* by pegmatitic granite.

The McCoy Mountains formation is extensively exposed in the McCoy Mountains, the southern Coxcomb Mountains (Pl. 5, fig. 2), and probably in the Palen Mountains. Most of this formation is a complex comprising metavolcanics (mainly original tuffs) together with some interbedded metasediments. It is thousands of feet thick and is either Late Paleozoic or Early Mesozoic, probably the former.

Mesozoic or Late Paleozoic intrusives.—Two intrusives—the Bradley granodiorite and the Fargo Canyon quartz diorite—are not younger than Late Mesozoic or older than Late Paleozoic. The Bradley granodiorite occurs in the Palm Springs-Indio

area. It varies from moderately foliated to highly foliated and granulated. It cuts the Palm Canyon complex, usually as sills. The massive to moderately foliated Fargo Canyon quartz diorite cuts the Chuckwalla formation sharply in the Little San Bernardino Mountains. The Fargo Canyon and the Bradley are probably correlatives. Chemical analysis, norm, and mode of the Fargo Canyon diorite are given in Table 2 (No. 15).

Late Mesozoic intrusives.—Three important Late Mesozoic intrusives are the generally massive San Jacinto granodiorite, the White Tank quartz monzonite, and the Coxcomb granodiorite so named from the regions in which they occur extensively. They are younger than any of the formations above mentioned and they are probably of the same general age. Chemical analyses, norms, and modes of the White Tank quartz monzonite and of the Coxcomb granodiorite are given in Table 2 (Nos. 14, 18).

Cenozoic dikes and volcanics.—Quartz latite porphyry dikes and basic (andesitic) dikes of Middle Tertiary age occur at various localities from the Mecca Hills to the Maria Mountains. Chemical analysis, norm, and mode of the quartz latite porphyry from near Desert Center are given in Table 3 (No. 26).

Olivine basalt, representing remnants of lava flows, cap several hills north of Desert Center. It is Late Tertiary or Early Quaternary.

TWENTY-NINE PALMS AREA

Introduction.—This area of 145 square miles includes a group of desert mountains extending from middle-southern San Bernardino County into middle-northern Riverside County. The geology of the area is similar to that of a much larger surrounding region which has not been mapped in detail, but which is fairly familiar to the writer. A geologic report (with map) on the Twenty-nine Palms area has been published by the writer (Miller, 1938), and, therefore, only a brief statement is presented here.

Early pre-Cambrian rocks.—The oldest known rocks of the area are highly metamorphosed sediments of which only a few scattered remnants are visible; these are too small to be mapped and are mainly gray quartzites and micaceous quartz schists.

The metasediments were intruded extensively by what is called the Gold Park gabbro of which there remain scattered, massive and foliated, mappable remnants. Chemical analysis, norm, and mode of a specimen of this rock are given in Table 1 (No. 19).

Most of the once widespread gabbro, together with the metasedimentary remnants, were then cut to pieces, foliated, and *lit-par-lit* injected by the magma of the Palms granite, leaving some rather massive remnants of the gabbro-diorite and very few remnants of the metasediments. One large and several small areas of the Palms granite are shown on the writer's map.

The intimate, usually banded, mixtures of the Palms granite and older rocks have been called the Pinto gneiss, which is prominently displayed. It is doubtless correlative with the Chuckwalla complex of the Palm Springs-Blythe area.

An interesting monzonitic porphyry in whose gray, medium-grained, massive to strongly foliated groundmass there are numerous, irregularly embedded, euhedral crystals of microperthitic orthoclase commonly from 1 to 6 inches in length resulted from crystallization of a syntectic magma produced by digestion of some of the Gold Park gabbro-diorite by the Palms granite porphyry.

All the above rocks are rather confidently believed to be Early pre-Cambrian (Miller, 1938, p. 438).

Late Mesozoic quartz monzonite.—Several bodies of light-gray, remarkably massive, uniform White Tank quartz monzonite cut all older rocks very sharply (Pl. 7, fig. 1). Two of these are stocks occupying fully 20 square miles each, and there are several much smaller bodies. Many dikes of aplite, and some of pegmatite, cut the monzonite which is quite certainly Late Mesozoic.

Tertiary dikes.—Fine-grained, basic dikes of gabbro-diorite composition cut all above-mentioned rocks sharply in many places. They are believed to be of about Middle Tertiary age.

Quartz latite porphyry (or rhyolitic) dikes sharply cut most of the other rocks, including the basic dikes, hundreds of them occurring in a restricted part of the area. These are no doubt of about Middle Tertiary age in common with similar dikes in various other parts of southern California.

RIVERSIDE AND WHIPPLE MOUNTAINS

Pre-Cambrian and Paleozoic? rocks.—The following statements are based upon brief visits by the writer to these two mountain areas; no published accounts of much importance are available. Metasediments several thousand feet thick, including crystalline limestones and quartzites with some associated gypsum beds, seem to constitute most of the eastern part of the Riverside Mountains about half way between Blythe and Parker Dam. These beds are probably correlative with those of the Paleozoic Maria formation of the Maria Mountains next to the south (Miller, 1944a, p. 25–28). In the eastern face of the mountains these metasediments rest unconformably upon variably impure, foliated granite quite certainly belonging with the Early pre-Cambrian Chuckwalla complex of the Maria Mountains.

The much more extensive Whipple Mountains, in the southeastern corner of San Bernardino County, consist largely or wholly of a metasedimentary-plutonic complex, which is probably Early pre-Cambrian.

Tertiary volcanics.—In the Whipple Mountains the complex is overlain by many areas of Tertiary volcanics, particularly in the eastern and western parts. The complex is much like some facies of the Chuckwalla complex in which impure granitic material prevails. The volcanics are mostly andesitic, much like those of the Sawtooth Range south of Needles (Miller, 1944a, p. 125–126) which are believed to be Middle Tertiary.

NEEDLES-GOFFS AREA

Introduction.—This important area of about 650 square miles is in the extreme eastern part of the Mohave Desert of San Bernardino County. Rugged hills and mountains, many with altitudes of several thousand feet, are flanked by alluviated valley floors. Since the writer (Miller, 1944c) has so recently described and mapped the geology of the area, only a brief summary of the crystalline rocks will here be given.

Early pre-Cambrian complex.—The oldest and most widespread rocks, comprising the Needles complex, are believed to be Early pre-Cambrian. This complex con-

sists mainly of diorite and metadiorite, locally with some metasediments, cut to pieces and often injected and migmatized or even assimilated by granite. Such assimilation has resulted in the development of a variably coarse-grained porphyritic gneiss in the northwestern part of the area. This is no doubt the Fenner gneiss of Hazzard and Dosch (1937, p. 309).

Paleozoic strata.—Next in age is a little crystalline limestone and quartzite bearing some poorly preserved fossils indicating a Carboniferous age. In addition to the area mapped by the writer, a small body of dolomitic limestone, with some magnesite, has been reported by Tucker and Sampson (1943, p. 534–535). It is about 2 miles south of the mapped area or 11 miles southwest of Needles. It is also quite certainly Paleozoic.

Late Mesozoic granodiorite.—Parts of several large bodies of massive granodiorite varying to quartz monzonite, and several small ones, cut the Needles complex sharply. They are regarded as Late Mesozoic. Chemical analysis, norm, and mode of a specimen of the granodiorite from 6 miles north of Goffs are given in Table 2 (No. 28).

Cenozoic dikes and volcanics.—Tertiary crystalline rocks, including hypabyssal and volcanic rocks, are, in order of age, quartz latite porphyry dikes, basic dikes, rhyolite porphyry dikes, and volcanic rocks which are mainly andesitic. These are all believed to be of Middle Tertiary age. Three of them are more or less widespread in southern California, but the rhyolite porphyry dikes, with their conspicuous flesh-colored phenocrysts, embedded in a gray, fine-grained groundmass, are exceptional. Chemical analysis, norm, and mode of a specimen of the rhyolite porphyry from 8 miles northeast of Goffs are given in Table 3 (No. 29).

Remnants of Early Quaternary basaltic lava flows occur as conspicuous caps on several small mountain peaks.

OLD WOMAN-PIUTE MOUNTAINS

Introduction.—These rugged, desert mountains in middle-eastern San Bernardino County extend north-south between Goffs and Milligan. They rise 500 to 3000 feet above the surrounding country. The northern part of the Piute Mountains has been mapped by the writer (Miller, 1944c, Pl. 7). The following data in regard to the Old Woman Mountains and the southern part of the Piute Mountains are based mainly upon mapping as shown on the state geologic map of 1938 and upon very brief published statements by Hazzard and Dosch (1937).

Early pre-Cambrian rocks.—According to available data a complex of Early pre-Cambrian rocks is widely exposed throughout most of these mountains. Hazzard and Dosch (1937, p. 308–309) say that this "Archean complex consists of three major units, all of which have undergone extensive regional metamorphism. From oldest to youngest, these are: (1) The Essex series of metamorphosed sedimentary rocks; (2) the Fenner granite gneiss; and (3) the Kilbeck granite gneiss." They say also that the Essex series, composed of quartz-biotite gneiss, marble, quartzite, mica schist, hornblende schist, and some altered igneous material, is exposed in the southern Piute Mountains, in the northern Old Woman Mountains, and at Chub-

buck in small foothills just southwest of the Old Woman Mountains; that the Fenner gneiss shows in the northern Piute Mountains, in the northern Old Woman Mountains, and at Chubbuck; and that the Kilbeck gneiss occurs at the southern end of the Old Woman Mountains. The writer believes that this Archean complex belongs in the same category as the Needles complex (Miller, 1944c, p. 116–119) but that it is generally much richer in definitely recognizable metasediments. From what the writer has seen of these metasediments in the southern Piute Mountains, for example along and near the highway 4 to 6 miles northeast of Essex, they are variably injected *lit-par-lit* by granite. Also considerable dioritic and metadioritic, variably granite-injected, material is associated with the complex. The Fenner gneiss, which is porphyritic, is interpreted by the writer as a granite-diorite syntectic (Miller, 1944c, p. 117–118). In order of age, the components of this complex, similar to those of the Needles complex, are: Essex metasediments, diorite and metadiorite, and Kilbeck granite with the associated Fenner gneiss representing a granite-diorite syntectic; the banded gneisses are granite-injected metasediments and metadiorite.

Hazzard and Dosch (1937, p. 309) state that the Essex series southeast of Fenner is overlain unconformably by Lower Cambrian? quartzite, thus pointing to a pre-Cambrian age of the above-described complex. They neither give the size of the quartzite area nor indicate other occurrences of Paleozoic rocks in the Piute and Old Woman Mountains.

Late Mesozoic quartz monzonite.—Throughout much of the mountains under consideration, there are small and large areas of massive granodiorite varying to quartz monzonite similar to that of the Needles-Goffs area, and also regarded as of Late Mesozoic age.

Tertiary volcanics.—There are several small areas of Tertiary volcanics, mainly andesitic, similar to those of the Needles-Goffs area, and also probably Miocene.

AMBOY-CADIZ AREA

Introduction.—Nearly all the crystalline rocks of this area are found in the Ship Mountains east of Cadiz, the Marble Mountains north of Cadiz, and the Bristol Mountains north of Amboy. These rugged desert mountains rise boldly 500 to 1500 feet above the alluviated valleys. A pre-Cambrian complex, Paleozoic fossiliferous strata, and Late Mesozoic plutonics are widely exposed with relationships unusually clear.

The most important reports, accompanied by maps, on the geology are by Darton (1915, p. 152–155) on the whole area, and by Hazzard and Crickmay (1933) on the Marble and Ship Mountains.

Early pre-Cambrian rocks.—A complex of rocks, which is with little doubt Early pre-Cambrian, is well shown in all three mountains. According to Hazzard (1933, p. 60) the complex includes "biotite and hornblende granite, diorite, gneiss, schist, and white marble," but this is all he says about it. Several areas are shown on his map. The following observations are by the writer. The complex is well exposed in several small and large areas in the southeastern two-thirds of the Marble Mountains, some small areas in the northwestern Ship Mountains, and typically and extensively in the southeastern Bristol Mountains. This complex is quite certainly of the same

general age as the Needles complex, and, as in the Old Woman-Piute Mountains, it contains considerable metasedimentary material.

Several square miles of the southeastern end of the Bristol Mountains are largely steep-dipping, highly crystalline limestone which is well bedded, in part dolomitic, and white to light gray with some bluish-gray beds. Some of the dolomite is foliated. There are also some interbedded, fine-grained quartzites and still less paraschist. These metasediments are cut by sill-like, and more locally cross cutting, bodies of a quartz monzonitic porphyry much like that described from the Marble Mountains (Pl. 3, fig. 1). It is also much like the Fenner gneiss of the Piute Mountains but it shows little or no foliation. This porphyry contains small and large, variably granite-soaked basic inclusions which seem to be metadiorite because there are some small bodies of massive to foliated undoubted diorite in the immediate vicinity. The metasediments, excepting the marble, have been locally granitized and somewhat *lit-par-lit* injected. The marble shows pronounced local deformation. These highly altered metasediments are so different from the practically unaltered Paleozoic strata of the Marble Mountains, next to the east, that they are certainly pre-Cambrian and very probably Early pre-Cambrian. Pre-Cambrian mixed rocks also occur extensively farther northwest in the Bristol Mountains, but they have not been examined carefully by the writer. In order of age, the members of the complex in the Amboy-Cadiz area are: Metasediments, diorite and metadiorite, and granitic rocks with the quartz monzonitic porphyry representing a granite-diorite syntectic. The metasediments probably correlate with the Essex series, the porphyry with the Fenner gneiss, and the granitic material with the Kilbeck granite gneiss, all of which occur in the Piute-Old Woman Mountains.

In the Marble Mountains, 4 miles north of Cadiz, a complex of variable diorite cut by dikes of pink, crudely gneissoid granite, together with some gray quartz monzonite porphyry (granite-diorite syntectic), lies unconformably under fossiliferous Lower Cambrian strata. Either side of the main highway, 2–3 miles north-northeast of Cadiz, there are extensive exposures of a quartz monzonitic porphyry with phenocrysts of pink potash feldspar, ranging in length to 1 inch, set in a gray, medium-grained groundmass. This massive rock, which seems to cut a dioritic rock, also lies unconformably under lower Cambrian beds. This porphyry is in all important respects much like that described from the Bristol Mountains. It is no doubt correlative with the Fenner gneiss farther northeast. No metasediments were seen in the Marble Mountains, but they may occur. In any case, the pre-Cambrian rocks of the Marble Mountains are confidently correlated with the Needles complex.

Paleozoic strata.—Little-altered strata of Paleozoic age are excellently exposed in the southeastern Marble Mountains and to a lesser extent in the Ship Mountains. Their occurrence is very significant not only because the Lower Cambrian part of the section rests unconformably upon the Needles complex, thus proving its pre-Cambrian age, but also because the Upper Paleozoic (Pennsylvanian and Permian?) strata are cut sharply by massive granite at several places, thus proving the post-Paleozoic age of the granite. The apparently conformable Paleozoic strata include Cambrian, Ordovician?, Silurian?, Devonian?, Mississippian, Pennsylvanian, and

Permian?. They consist of several thousand feet of common kinds of sedimentary rocks with limestones and dolomitic limestones particularly abundant. The Cambrian beds were first recognized by Darton (1907) and later studied by Clark (1921), Hazzard and Crickmay (1933), and Hazzard and Mason (1936). The later Paleozoic strata are described briefly by Hazzard (1933).

Late Mesozoic quartz monzonite.—Fairly large bodies of quartz monzonite sharply cut not only the Needles complex but also the Paleozoic strata, including the youngest, in several parts of the Marble and Ship Mountains. Similar rock cuts the Needles complex near the southeastern end of the Bristol Mountains. It is a pinkish-gray, massive, medium-grained quartz monzonite. Chemical analysis, norm, and mode of a specimen from the area 6½ miles north-northwest of Cadiz are given in Table 2 (No. 9). This quartz monzonite is certainly post-Paleozoic and quite probably Late Mesozoic.

A spot of exceptional geologic interest is in the Marble Mountains, 6 miles north-northeast of Cadiz, where the pre-Cambrian Needles complex, Paleozoic strata, and Late Mesozoic quartz monzonite come together with relationships very clearly exhibited (Pl. 4, fig. 1).

Cenozoic volcanics.—Tertiary volcanic rocks, probably of Miocene age, occur in small and large areas in the Marble and Ship Mountains as shown on Hazzard's map (1933), and also extensively in the middle and northwestern parts of the Bristol Mountains. These include rhyolites, andesites, basalts, tuffs, and agglomerates. Some intrusive plugs are included.

Small patches of what are probably Quaternary volcanics, mainly basalts, occur in the Bristol and Marble Mountains, and just northwest of the Ship Mountains. Mention should be made of the cinder cone and field of basaltic lava a little southwest of Amboy. As stated by Darton (1915, p. 154) "This lava is, geologically, very recent and may have flowed out over the bottom of the basin within the last thousand years. It covers a nearly circular area about 5 miles in diameter."

PROVIDENCE MOUNTAINS

Introduction.—These desert mountains, in east-central San Bernardino County, extend nearly north-south. They are north of the Marble Mountains or east and southeast of Kelso. They reach altitudes of 6000 to 7000 feet and they generally rise boldly several thousand feet above the surrounding country.

The geology of the Providence Mountains is very much like that of the Marble Mountains. For this reason, and also because they have been mapped by Hazzard (1933), brief statements only will here be made with some comments based upon observations by the writer.

Early pre-Cambrian complex.—This complex, believed to belong in the category of the Needles complex, is extensively developed in the southern and northern parts of the mountains. Hazzard does not describe these areas, and the writer is not very familiar with them. The writer has, however, examined an area of 6 or 7 square miles of the complex which forms a hilly spur of the mountains a few miles east of the middle of the main range. This area, not shown on Hazzard's map, consists largely

of a more or less intimate mixture of Early pre-Cambrian dioritic and granitic rocks. Much of the mixture seems to be granite-soaked, or partially digested, coarse-grained dioritic gneiss in which remnants of the diorite are more or less unaffected.

Paleozoic strata.—Hazzard's map shows an extensive development of Paleozoic strata in the middle part of the Providence Mountains. According to his description, they range from Early Cambrian to Permian, with most of the systems represented. East of Kelso the Lower Cambrian rests unconformably upon the Early pre-Cambrian complex. The Middle Cambrian of the Providence Mountains has been described in detail by Hazzard and Mason (1936).

Triassic strata.—Hazzard (1937) says that some Lower Triassic marine strata lie unconformably upon Permian limestone in the central portion of the Providence Mountains.

Late Mesozoic intrusives.—A number of fairly large bodies of Late Mesozoic, massive granite or quartz monzonite cut both pre-Cambrian and Paleozoic rocks sharply in the southern half of the mountains. Similar rock cuts the pre-Cambrian complex in the hills a few miles east of the main range.

Special mention should be made of the large area of massive granite (or quartz monzonite) on the northern side of the Providence Mountains. On the state geologic map of 1938, it is shown as "Tertiary granitic rock." The writer is certain that, in the general vicinity of Gold Valley Spring, the Tertiary volcanics are younger than this intrusive body and lie upon it. Examination of this intrusive body by the writer shows that it is remarkably like the Late Mesozoic quartz monzonite, varying to granite, which is so widespread in southern California. Certainly there must have been profound erosion to lay bare such a large plutonic mass before the Middle Tertiary volcanics spread over it. The age of a similar intrusive, in the northwestern corner of the Needles-Goffs area, has been discussed by the writer (Miller, 1944c, p. 121). The conclusion is that these two so-called Tertiary intrusive granites are probably Late Mesozoic but possibly very Early Tertiary.

Tertiary dikes and volcanics.—In the hilly mountain spur a few miles east of the main range, the Needles complex is cut sharply by large, crudely parallel, rhyolite porphyry dikes like those described from north of Goffs in the Needles-Goffs area (Miller, 1944c, p. 123–124), and regarded as of Middle Tertiary age.

Middle or Late Tertiary volcanics, including andesites, rhyolites, and pyroclastics, occupy several small and large areas in various parts of the mountains. The largest area forms a conspicuous plateau 6 miles across, in the northeastern part of the Providence Mountains. These volcanics are not cut by the above mentioned rhyolite porphyry dikes which are so prominent just south of the plateau.

BAKER AREA

Introduction.—A varied and interesting lot of rocks occurs in the mountains in the general vicinity of Baker. The only geologic map of importance known to the writer is the small-scale part of the 1938 state map which needs revision for the Baker area. Most of the following statements are based upon reconnaissance work by the writer, but detailed field work is necessary for more satisfactory solution of several important problems.

Early pre-Cambrian rocks.—The writer proposes to call the Early pre-Cambrian complex including, in order of age, metasediments, variably altered and granitized diorite, and variably altered granite the Halloran complex because of the excellent exposures in the area of about 40 square miles of small mountains extending from the general vicinity of Halloran Spring westward to north of Silver Lake village. Since the best and most typical exposures occur in the vicinity of Silver Lake, the complex might better be named after that locality, but the name is preoccupied.

Excellent exposures of the Halloran complex, 1–3 miles northeast of Silver Lake village, show much steep-dipping crystalline limestone, in part dolomitic, associated with some paraschists. These metasediments are cut by considerable diorite which is variable in composition and structure. Both metasediments and diorite are cut by much granitic material which has more or less reacted with dioritic material to produce a contaminated granite or medium-grained syntectic locally with scattering phenocrysts of potash feldspar ranging to 1 centimeter in length. Often the metadiorite and paraschist of this area have been variably granitized and *lit-par-lit* injected by the granite with development of crudely banded gneisses so characteristic of Early pre-Cambrian rocks in many parts of southern California. This complex is almost exactly like the pre-Cambrian Needles complex in the Amboy-Cadiz area, but the syntectic porphyry (Fenner gneiss?) with the large potash feldspar phenocrysts is not so strikingly developed. Between 3 and 7 miles north and northeast of Silver Lake Village the rocks of the complex are more or less intimate mixtures of diorite, metadiorite, and variably contaminated granite cut by some pegmatites. In the vicinity of the talc mine, 9 miles northeast of Silver Lake village, much metasediment again shows in what is probably the Halloran complex, but the writer's acquaintance with this locality is very casual. The highly metamorphosed strata of the areas just described are quite certainly much older than the less-altered, noninjected, fossiliferous Paleozoic limestone just west of Baker not far to the south.

In the vicinity of Halloran Spring there occurs more of the contaminated granite, or diorite-granite syntectic, which is somewhat porphyritic. This rock is cut sharply by aplitic granite dikes which may be Late Mesozoic. For several miles west and southwest of the spring, the rocks are largely diorite and metadiorite irregularly cut to pieces by much granite and relatively little affected by it. This part of the complex is much like that of the Needles complex (Miller, 1944c, p. 116) 10 to 15 miles south of Needles. The state geologic map of 1938 shows an area of Early Tertiary granitic rocks covering many square miles from the vicinity of Halloran Spring westward, but the writer believes that this area consists of the Halloran complex, mainly dioritic and granitic rocks, largely, if not wholly, very much older than Early Tertiary, that is Early pre-Cambrian. A thin section of the diorite or somewhat granitized diorite from near Halloran Spring shows it to be a biotite and hornblende-rich diorite containing a little potash feldspar and quartz, and considerable epidote. The texture is medium-grained and hypidiomorphic. A very similar diorite lies unconformably under the Paleozoic limestone on the western and northern sides of the hill just west of Baker, thus indicating strongly that the diorite of the Halloran complex is pre-Paleozoic. Similar granite-contaminated diorite also underlies the Paleozoic limestone in the small mountain 10–12 miles south-southeast of Baker.

The range of hills extending north-northwestward from 1 mile northwest of Baker to west of Silver Lake consists largely, or wholly, of the Halloran complex much like that northeast of Silver Lake. These hills are shown on the 1938 state geologic map as Paleozoic metasediments.

The prominent spur, extending from the top of the Soda Mountains 6 miles southeastward to the main highway 5 miles south-southeast of Baker, consists mainly of the Halloran complex including a wide belt of light-brown crystalline limestone.

Paleozoic strata.—Moderately metamorphosed, mainly bluish-gray limestone constitutes most of the high, rugged hill just west of Baker. Some poorly preserved fossils, found in this limestone by Thompson (1929, p. 557), were determined as Carboniferous. Crinoidal remains found by the writer were pronounced Carboniferous by Dr. G. Arthur Cooper of the United States National Museum and Dr. Edwin Kirk of the United States Geological Survey. They are probably Mississippian. Similar limestone seems to occur in the foothill belt for some miles northwest of Baker, but the writer has not studied this occurrence. Small hills 2 and 7 miles, respectively, southeast of Baker are believed to consist of limestone like that just west of Baker.

Beginning about 3 miles west of Baker, a belt of limestone, probably like that just west of Baker, extends west-northwestward for several miles, but it has not been studied by the writer.

Late Mesozoic quartz monzonite.—A gray, massive, medium to moderately coarse-grained quartz monzonite is well exposed 6 to 8 miles southwest of Baker along the main highway and south of it for at least 2 miles. Nearly two-thirds of the rock is gray microperthitic feldspar, one-third is quartz, and small amounts of mafic minerals make up the rest. Chemical analysis, norm, and mode of a specimen of this rock are given in Table 2 (No. 20). The relation of this rock to other formations was not observed. It is tentatively assigned to the Late Mesozoic although its gray feldspar is exceptional in plutonic rocks of this age in southern California.

As already suggested, the aplitic granite dikes cutting the pre-Cambrian dioritic rocks near Halloran Spring may be Late Mesozoic or even Early Tertiary. If so, there may be larger bodies of quartz monzonite or granite of such younger age northeast or east of Halloran Spring.

Cenozoic dikes and volcanics.—A small quartz latite porphyry dike cuts the limestone in the hill just west of Baker. It is probably like the Middle Tertiary dikes of the Needles-Goffs area (Miller, 1944c, p. 121–122). Other similar dikes may occur.

Some small basic dikes, no doubt of Middle Tertiary age, cut the Halloran complex in the little hill 1 mile north of Silver Lake village.

Volcanic rocks of Tertiary, probably Miocene, age are not common in the general vicinity of Baker, but there are relatively small areas 16–18 miles north-northeast, 10–12 miles southeast, and 4–5 miles southwest of Baker.

Early Quaternary (or Late Pliocene) volcanics are rather extensively shown in two areas, one of them extending some miles north-northeastward from near Halloran Spring, and a much larger area southeast and south of the same place, as shown on the 1938 state geologic map.

A small but conspicuous cap of Early Quaternary or Late Tertiary basaltic lava covers an outcrop of pre-Cambrian diorite at the north base of the high hill just west of Baker.

NEWBERRY MOUNTAINS-LUDLOW AREA

Introduction.—This extensive area lies in the midst of the Mohave Desert, just southwest of the center of San Bernardino County. It consists of typical, rugged, desert mountains, many of which rise to altitudes of 3000 to 6300 feet, separated by broad, alluviated desert basins with altitudes of 1000 to 3000 feet.

A rather generalized, small-scale geologic map of part of the area has been published by Darton (1915, sheet no. 23). Most important, however, is the geologic report by Gardner (1940) who has mapped fully 1000 square miles of the area. His map shows the geology of two parts of the area—one including the Newberry, Ord, Fry, and Lava Bed Mountains, and the other an area east and northeast of Ludlow, including the northern Bristol Mountains. Between the two parts a wide belt, including the Cady Mountains, is left geologically unsurveyed.

The Newberry Mountains-Ludlow area contains an array of crystalline rocks ranging from Early pre-Cambrian to Late Quaternary. Because Gardner's report covers so much of the area, only a brief summary of the crystalline rocks, as determined by him, will now be given, with some differences of interpretation based upon observations by the present writer.

Early pre-Cambrian rocks.—The oldest rocks are regarded as Early pre-Cambrian. According to Gardner (1940, p. 262-264) these "Archean" rocks consist of metasediments and younger plutonics. The metasediments were found in only a few small areas, scarcely large enough to show on the map. Eighteen areas of plutonics, ranging from a fraction of a square mile to 8 or 9 square miles, are mapped. These are mostly diorite and metadiorite with some granite porphyry. The most important occurrence of metasediments is in Kane Canyon 1–1½ miles east of Kane Springs in the Newberry Mountains. Gardner says that an areal outcrop of less than half a square mile consists of interbedded gneiss, marble, and quartzite, with a biotite-orthoclase gneiss greatly predominant, and with some "orthoclase quartzite" and "biotite quartzite." He suggests that the feldspathic rocks may represent either metamorphism of interbedded feldspathic sediments or replacement of original constituents by feldspar. In any case he believes that the rocks are very largely, if not wholly, metasediments. The present writer, having made observations on the same occurrence in Kane Canyon, offers a different interpretation. In the eastern part of the area, facing the "narrows" of Kane Canyon, there is a large exposure of steep-dipping, well-bedded marble. It is mostly white with some bluish-gray beds, and with some associated quartzite. This marble is cut by diorite, varying to metadiorite (or amphibolite), and the latter is cut and variably assimilated or digested (within 100 feet of the marble) by gray to pinkish-gray granite. The quartzite has also been somewhat granitized. Near the diorite contact, some crudely rounded masses of both diorite and granite, ranging to several feet in diameter, have been kneaded into the marble. The granite-diorite digestion product is a porphyritic

biotite gneiss regarded as a syntectic which is conspicuously exposed in the wall of Kane Canyon for half a mile west of the "narrows." Numerous pinkish-gray, subhedral orthoclase phenocrysts, ranging in length to 1 inch, are scattered through the fairly uniform gneiss. The Kane Canyon occurrence is, therefore, a complex of highly altered sedimentary and plutonic rocks similar, in all important respects, to occurrences regarded as of older pre-Cambrian age in many parts of southern California.

Paleozoic? metasediments.—Gardner (1940, p. 264–266) says that certain quartzites and marbles, tentatively referred to the Paleozoic, are sparsely distributed within the Newberry Mountains-Ludlow area. They may belong with the Oro Grande metasediments of Carboniferous age in the vicinity of Victorville (Miller, 1944b, p. 98–100).

Triassic? volcanics and intrusives.—Gardner's Ord Mountain group of probable Triassic age consists of older andesitic flows, tuffs, volcanic breccia, and a younger hypabyssal intrusive metaporphyry. They occupy several areas. Very recently the writer has seen something of these moderately altered igneous rocks, and he no longer believes that they can possibly be correlatives of the highly metamorphosed Late Paleozoic Sidewinder Valley metavolcanics of the Victorville region not far to the southwest (Miller, 1944b, p. 102).

Late Mesozoic plutonics.—A plutonic sequence of Late Mesozoic age is prominently developed and widespread. Gardner (1940, p. 270) says that these rocks, in order of age, are: quartz monzonite, pink granite, Cactus granite, and quartz porphyry. The Cactus granite, regarded as correlative with the rock so named from its type locality in the middle-northern San Bernardino Mountains (Vaughan, 1922, p. 365), seems to be, for most part, quartz monzonite as shown by Gardner (1940, p. 274). A thin section of the "pink granite" from the area 5 miles south of Daggett, examined by the writer, also is quartz monzonite. It shows by volume percentages: microperthite, 40; microcline, 5; quartz, 25; oligoclase, 26; biotite, 1½; magnetite, 1½; sphene, 1; and traces of apatite.

Cenozoic dikes and volcanics.—It is very doubtful if Gardner's quartz porphyry belongs with the plutonic sequence. It occurs in several areas which the state geologic map of 1938 shows as Tertiary intrusives. Petrographically (Gardner, 1940, p. 275) the rock is much like the writer's quartz latite prophyry dikes constituting prominent dike systems in various parts of southern California, as for example in the Needles-Goffs area (Miller, 1944c, p. 121–122). These dikes are of Early or Middle Tertiary age, and, like the quartz porphyry, they are older than adjacent volcanics of Middle Tertiary age.

Numerous acidic (rhyolitic) dikes, followed by basic dikes, are fairly widespread. They are probably of Middle Tertiary age (Gardner, 1940, p. 278).

According to Gardner (p. 279–288) Late Tertiary lava flows, tuffs, and agglomerates, associated with Rosamond sediments, are followed by Late Tertiary (Pliocene?) Red Mountain andesite. These are followed in turn by Quaternary Black Mountain basalt; rhyolite flows and tuffs; basalt and rhyolite flows; and the Sunshine and Pisgah basalt flows and cones. The last two are certainly Late Quaternary (or Recent) and much like the occurrence near Amboy.

BARSTOW QUADRANGLE

Introduction.—The Barstow quadrangle lies in middle-western San Bernardino County. Two large parts of the quadrangle have been described and geologically mapped by the writer (Miller, 1944b, p. 73–112). One of these (Victorville area), comprising an area of about 175 square miles, forms the middle-southern part of the quadrangle, and the other (Barstow area), comprising an area of about 220 square miles, forms the northeastern part of the quadrangle. Within the two mapped areas, altitudes range from 2100 feet to more than 4500 feet. Numerous desert hills and mountains, separated by relatively wide desert basins, rise to heights ranging from a few hundred feet to nearly 2000 feet above the surrounding country. The Mojave River flows across both mapped areas.

Hershey (1902a, p. 283, 286–289) published brief statements on "Mesozoic granite" near Victorville, the "Archean? gneiss" near Barstow, and the "Oro Grande series" of metasediments near Oro Grande. Pack (1914, p. 144–145) published some brief statements, accompanied by a reconnaissance geologic map, on the crystalline rocks north and west of Barstow. In a paper by Darton (1915, p. 162–164), rocks near the railroad between Barstow and Victorville are described briefly and mapped in a general way. Some idea of the crystalline rocks of the Barstow quadrangle may be gained from the small-scale, reconnaissance geologic map of the Mohave Desert by Thompson (1929, Pl. 8).

Since the kinds, ages, and distribution of the crystalline rocks of much of the quadrangle have been so recently reported on by the writer (Miller, 1944b) a brief summary only will now be given, followed by heretofore unpublished notes on the rocks in the general vicinity of Stoddard Well.

Paleozoic rocks.—Late Paleozoic strata (Mississippian?) are well represented, in the Victorville area, by the Oro Grande metasediments comprising thousands of feet of crystalline limestones and quartzites. Some poorly preserved fossils have been found in the limestone by the writer.

In the Victorville area, the Sidewinder Valley metavolcanics are well exhibited (Pl. 5, fig. 1). These consist of original lavas and tuffs, thousands of feet thick, which are now much altered and usually strongly foliated, even highly schistose. In some places they are interbedded with the Oro Grande metasediments.

Paleozoic and/or Mesozoic complexes.—The oldest of these rocks are largely metasediments, mostly crystalline limestones with some associated quartzites and schists. They are in many places cut more or less intimately, usually parallel to the bedding (or foliation), by dioritic, granitic, pegmatitic, and silexitic material; the diorite (often metadiorite) the oldest intrusive. Where the igneous materials are very subordinate, the mixture is mapped as the Hinkley Valley complex, and where the igneous materials greatly predominate, or alone are present, it is mapped as the Hodge complex; the two complexes are not sharply separable. In places the granitic material has locally injected *lit-par-lit* and digested older rocks. These complexes occur in the Barstow area. In the writer's report (Miller, 1944b, p. 79, 97-98) they are regarded as Paleozoic or older, with the probability favoring a pre-Cambrian age. However, the finding of presumably Late Paleozoic crinoidal segments in limestone

of the near-by Paradise Spring complex, which is almost exactly like the Hinkley Valley complex, indicates strongly that the latter complex is also partly, if not wholly, Paleozoic. Accordingly, the diorite and granite of the Hodge complex are Late Paleozoic or Mesozoic; the granite quite surely is Late Mesozoic.

Since publication of the writer's 1944 paper on the Barstow area, some doubt has been expressed as to the age of the yellowish-brown crystalline limestone forming the two hills about a mile north of Barstow (Miller, 1944b, p. 78), with the suggestion that they are probably Tertiary. The writer, however, rather confidently believes that this limestone is part of the Hinkley Valley complex; the same kind of limestone is intimately associated with both the Hinkley Valley and Hodge complexes a few miles west-northwest and northeast of Barstow. Early in 1945 the writer saw similar crystalline limestone interbedded with other metasediments which have been variably granite-injected and granitized on the plateau 3–6 miles east of Barstow. These mixed rocks are certainly part of either the Hinkley Valley complex or the Hodge complex.

Mesozoic or Late Paleozoic basic intrusives.—These intrusives cut the Paleozoic metasediments sharply. The gabbro-diorite of Iron Mountain is confined to one important part of the Barstow area, and the Bell Mountain quartz diorite occurs in several parts of the Victorville area.

Late Mesozoic quartz monzonite.—The Victorville quartz monzonite varying to granodiorite occurs in various small and large bodies in the Victorville area. It has satellitic dikes of granite, aplite, and pegmatite. It cuts both the Bell Mountain diorite and the Oro Grande metasediments. Chemical analyses, norms, and modes of the Bell Mountain quartz diorite and of the Victorville granodiorite are given in Table 2 (Nos. 17, 8).

Tertiary dikes and volcanics.—Quartz latite porphyry dikes cut the country rocks sharply in various parts of the Barstow and Victorville areas. They are probably of Middle Tertiary age, and much like those already referred to in the Needles-Goffs area, Desert Center area, and other parts of southern California.

Tertiary volcanic rocks occupy a number of small and fairly large areas in the Barstow quadrangle. They range from andesite to rhyolite and include both lava flows and pyroclastics, with the lavas predominant. They are probably correlative with the Pliocene Red Mountain andesite of the Randsburg area (Hulin, 1925, p. 42–46) and the Pliocene? Red Mountain andesite of the Newberry Mountains (Gardner, 1940, p. 281, 283).

Rocks of Stoddard Well vicinity.—The writer has also done considerable field work on the crystalline rocks in the general vicinity of Stoddard Well, in the middle-eastern border portion of the Barstow quadrangle.

The group of high hills, covering several square miles 5–7 miles north-northeast of Stoddard Well, consists mainly of dioritic rocks cut to pieces and variably digested by granitic material. These rocks may belong with the Hodge complex, but they may be pre-Cambrian.

A complex much like that just described occupies the group of hills extending several miles north of Stoddard Well; a syntectic porphyry containing pink orthoclase phenocrysts, as much as three-fourths of an inch in length, is common. This com-

plex may also be pre-Cambrian. A wide belt of rather coarse-grained, massive, Late Mesozoic quartz monzonite cuts the porphyry across the northeastern flank of the hills and extends southeastward for 2 miles across the road. These rocks are cut sharply by many quartz latite porphyry dikes of Middle Tertiary age like those of the Barstow and Victorville areas.

Stoddard Ridge, extending 6 miles east-southeastward from Stoddard Well, contains various crystallines, most of its northern and eastern parts consisting of a complex which is mainly massive to foliated, coarse-grained to fine-grained, dark-gray dioritic material intimately associated with some granitic material. It may belong with the Hodge complex or it may be pre-Cambrian.

An area of Triassic? metaporphyry mapped by Gardner (1940, Pl. 2) enters the Barstow quadrangle at the eastern end of Stoddard Ridge.

Two small bodies of Bell Mountain diorite were found—one cutting the complex just east of Stoddard Well, and the other lying in, and cut by, quartz monzonite.

A body of massive Late Mesozoic quartz monzonite, more than a mile wide, extends from 1 mile south of Stoddard Well eastward for several miles including the highest part of the ridge. It cuts the neighboring complex sharply and sends many dikes into it. Many of the Middle Tertiary quartz latite porphyry dikes and fine-grained basic dikes—some of the latter cutting the former—sharply cut all the other rocks of Stoddard Ridge.

The state geologic map of 1938 indicates that Stoddard Mountain, just southwest of Stoddard Sell, consists of a Tertiary instrusive. Very recently, however, the writer, after examining the eastern face of the mountain, concluded that it consists of volcanic rocks (including tuffs) much like those of the Victorville and Barstow areas. These volcanics rest upon diorite-granite mixed rocks. One of the large Middle Tertiary quartz latite porphyry dikes, but by a basic dike, passes under these volcanics.

PARADISE SPRING AREA

Introduction.—This area of several hundred square miles extends from the general vicinity of Langford Well west-southwestward to the general vicinity of Coolgardie. It is north and northeast of Barstow, most of it in the southwestern corner of the Avawatz quadrangle. Various small, rugged, desert mountains rise hundreds of feet to more than 2000 feet above small alluviated valleys.

The only geologic map of any importance covering the area is the small-scale, much generalized part of the map of the Mohave Desert accompanying the report by Thompson (1929, Pl. 8). A few scattered remarks on the crystalline rocks are included in that report. A reconnaissance map of the Barstow-Kramer region by Pack (1914) includes the southwestern border of the area. Erwin and Gardner (1940, p. 293-297, Pl. 3) have reported on the southern flank of the Calico Mountains.

The following notes are based upon observations by the writer who spent about a week in the area.

Paleozoic and Mesozoic rocks.—The oldest rocks of the area seen by the writer are extensively exposed in the Paradise Mountains west of a line running northeasterly through Paradise Spring. These are steep dipping metasediments, probably thou-

sands of feet thick. They are largely white and bluish-gray crystalline limestones (some dolomitic), with considerable associated gray, fine-grained, thin-bedded quartzite and slaty schist. These beds have been cut by sills and dikes of diorite. This combination has been locally and variably granitized, silexitized, and *lit-par-lit* injected with some granitic material mainly in the border zone, about half a mile wide, along the eastern side of the metasediments. In this border zone the metasediments are cut to pieces irregularly by the diorite, and the combination is cut irregularly by many aplitic granite and pegmatitic granite dikes. The granitic material is often impure due to contamination. The metasediments of the zone are also cut by a good deal of contaminated silexite which more or less replaces sedimentary beds. The diorite of the zone varies from medium to moderately coarse-grained, and from massive to strongly foliated. It is also variable in composition. This complex is, in all important respects, so much like the Hinkley Valley complex of the near-by Barstow area (Miller, 1944b, p. 77–79) that both are rather confidently believed to be partly, if not wholly, of the same age. In 1945 the writer found some small, imperfectly preserved crinoidal segments in bluish-gray limestone of the complex near Paradise Spring. These are much like crinoidal fragments occurring in similar bluish-gray, Paleozoic (Mississippian?), crystalline limestone, associated with some white dolomitic marble, at Baker 40 miles farther east, and in similar limestone of the Mississippian? Oro Grande formation in the vicinities of Oro Grande and Victorville 45–50 miles to the southwest. The metasediments of the complex are, therefore, partly, if not wholly, of Paleozoic (Mississippian?) age. In some places, Oro Grande paraschist has also been cut by diorite and locally injected by granite *lit-par-lit*, as for example about 2½ miles east of Oro Grande.

The rocks of the Paradise Mountains east of the Hinkley Valley complex are plutonics with no sharp contact between the two lots of rocks. These plutonics consist mainly of gray, massive, medium-grained quartz diorite which is locally variable in composition and somewhat foliated. Here and there this diorite has been cut to pieces, partly digested, and *lit-par-lit* injected by granitic material. There are some well-defined granite dikes, particularly about 1–2 miles southwest of Paradise Spring. The diorite and granite of this plutonic complex are the sources of the intrusive material found in the adjacent metasediments.

The plutonic complex just mentioned is rather confidently classed with the Hodge complex of the near-by Barstow area, particularly where that complex contains little or no metasediment (Miller, 1944b, p. 79–80, 97–98). The Hodge complex was regarded as Paleozoic or older, probably Early pre-Cambrian, because of some local resemblances to known Early pre-Cambrian complexes in southern California. However, the very recent finding of fossil remains in the metasediments of the Paradise Mountains shows that the dioritic and granitic rocks of the plutonic complex in those mountains must be Late Paleozoic or Mesozoic because they cut the Paleozoic metasediments. The diorite may possibly be Late Paleozoic, as may also the Sacatar diorite of the Kernville quadrangle (Miller and Webb, 1940, p. 356–357) and some diorite still farther north in the Sierra Nevada, but the grainite is quite certainly Late Mesozoic. It may be noted in this connection that the Bell Mountain diorite, which cuts Paleozoic (Mississippian?) strata near Victorville, has locally been

cut to pieces and variably injected by Victorville quartz monzonite with production of a complex (Miller, 1944b, p. 103–104) similar to that of the diorite-granite complex of the Paradise Spring area.

Rocks of the Hodge? complex, similar to those just described, are widely exposed in the hills just north and northeast; 2–4 miles west; and 3–6 miles south-southwest of Langford Well. A thin section of granite from the last-named area shows by volume percentages: microcline, 54; quartz, 30; acidic oligoclase, 15; magnetite, $\frac{3}{4}$; and zircon, $\frac{1}{4}$. It is inequigranular and it shows some evidence of crushing. Other similar rocks of the diorite-granite complex occur in a belt (crossed by the highway) at the northern base of the Calico Mountains; both east and southwest of Coolgardie; and in the hills 5 miles northeast of Collgardie. A large body of the generally massive diorite, cut sharply by a good many granite, aplite, and pegmatite dikes, is well exposed in the eastern flank of Lane Mountain and extends several miles north. In the canyon at the north base of Lane Mountain there is a xenolith of fine-grained, thin-bedded quartzite in the diorite. It no doubt belongs with the Paleozoic metasediments of the Hinkley Valley complex.

A body of pinkish-gray, massive, medium-grained quartz monzonite or granite, several miles long and more than 1 mile wide, extends from just south of Lane Mountain westward across the Randsburg-Barstow highway. It cuts the diorite southeast of Lane Mountain and it is quite certainly Late Mesozoic.

Late Cenozoic volcanics.—The calico Mountains consist of Tertiary volcanics with much associated sedimentary material. The oldest, which are probably Miocene, include andesitic and rhyolitic lava flows, tuffs, volcanic breccias, and agglomerates. "Lying more or less unconformably on top of the volcanic mass of rock are sedimentary lake beds and associated tuffs and flows" (Erwin and Gardner, 1940, p. 297). The lake beds (Rasamond?) are Late Miocene or Early Pliocene. Still younger is the Red Mountain andesite of Pliocene? age. The whole Tertiary volcanic-sedimentary series is thousands of feet thick. A considerable body of the Hodge? complex, crossed by the highway at the northwestern base of the Calico Mountains, plainly underlies the volcanics. About 2 square miles of Tertiary volcanics, hundreds of feet thick, form the top of Lane Mountain. Tertiary volcanics also occur in several areas north of Coolgardie. Mention may be made of the well-known "Barstow fossil-beds" (Rosamond?) of Late Tertiary age widely exposed in the southwestern part of the Paradise Spring area.

The Black Mountain basalt of Early Quaternary age covers an area of approximately 35 square miles northwest of Coolgardie. It forms a thick cap on the older rocks of Black Mountain and vicinity.

SHADOW MOUNTAINS-WILSONA AREA

Introduction.—This area of about 250 square miles includes the Shadow Mountains near the middle-western border of San Bernardino County and the general vicinities of Hi Vista, Wilsona School, and Black Butte in the northeastern corner of Los Angeles County. The Shadow Mountains, 12 miles in length, in the eastern part of the area, rise as much as 800 feet above the wide alluvial slope almost completely surrounding them. Shadow Peak is the highest point with an altitude of about 4000

feet. The larger, western part of the area contains many isolated hills and small mountains, and a wide, low, domelike feature about 8 miles in diameter, around Hi Vista.

Little or no important published statements on the crystalline rocks of the area seem to be available. The following notes are based upon 5 days of reconnaissance field work by the writer.

Paleozoic strata.—Metasedimentary rocks are widely and excellently exposed in the Shadow Mountains. Thus the whole southeastern flank of the mountains, forming a belt 1½ to 2 miles wide and 5 miles long, is largely or wholly moderately metamorphosed, well-bedded, mostly bluish-gray limestone. Similar limestone, with some associated quartz-mica schist, forms the foothills between 5 and 7 miles north-northwest of Adelanto. The limestone is cut sharply by some aplite dikes which are no doubt offshoots of the near-by quartz monzonite. The wide northeastern spur of the Shadow Mountains, extending from the west flank of Shadow Peak 5 miles eastward, also consists of the limestone, but it has been only casually observed by the writer. This limestone series of the Shadow Mountains seems to be at least several thousand feet thick. No fossils were found in it, but it is rather confidently correlated with the very similar Oro Grande metasediments of the near-by Victorville area.

Paleozoic and/ or Mesozoic complex.—Mirage Hill, about 7 miles east-southeast of Wilsona Ranch, consists mainly of dark dioritic material varying from gneissoid diorite to metadiorite and schistose amphibolite. These rocks are cut to pieces by medium- to fine-grained, rather massive, biotitic granite. This mixture probably belongs with the Hodge complex of the Barstow area (Miller, 1944b, p. 79–80, 97–98). No other rocks of this kind were seen in the area.

Mesozoic or Late Paleozoic diorite.—Black Butte, 5 miles southeast of Wilsona Ranch, consists almost wholly of a diorite which is mainly dark gray, massive, medium-grained, and granitoid. Locally, it shows primary foliation, and variations in grain size and composition. It is tentatively correlated with the Bell Mountain diorite (Miller, 1944b, p. 103) of the Victorville area not far to the east. It is cut by the next-mentioned quartz monzonite.

Late Mesozoic quartz monzonite.—The long ridge of the Shadow Mountains, connecting the two limestone areas, is all or nearly all medium-grained, massive, light-gray quartz monzonite. It cuts the limestone and is quite certainly the same age as the Late Mesozoic Victorville quartz monzonite of the near-by Victorville area. All the numerous outcrops observed throughout the western two-thirds (or Los Angeles County portion) of the Shadow Mountains-Wilsona area, extending as far as 5 miles west of Wilsona School, are the same quartz monzonite, with minor variations. The areal extent of this monzonite, therefore, seems to be at least 200 square miles.

Tertiary dikes and volcanics were not seen in the area, but some may occur.

RANDSBURG AREA

Introduction.—This area of about 175 square miles, in the northwestern part of the Mohave Desert, comprises all but a northwestern strip of the Randsburg quadrangle.

It includes the Rand Mountains, Red Mountain, and the Lava Mountains with maximum altitudes of 4755, 5270, and 4985 feet, respectively. These mountains commonly rise 1000 to 2000 feet above adjacent alluvium-filled valleys.

The only important descriptions of the crystalline rocks of the area are those by Hess (1909, p. 27-31) and by Hulin (1925). Hulin's detailed study is accompanied by a geologic map, and, therefore, only a brief summary of his work, accompanied by some observations by the writer, will here be given.

Pre-Cambrian rocks.—The "Johannesburg gneiss," which includes the oldest rocks of the quadrangle, is exposed only in two relatively small areas. The larger of these lies about 2 miles north of Johannesburg. According to Hulin (1925, p. 21–23) it consists largely or wholly of metasediments, mainly banded hornblende-pagioclase gneiss, together with some intercalated, white, coarsely crystalline limestone and still less quartzite. He says that the hornblende gneiss may be of igneous origin. The writer's interpretation is that the steep-dipping metasediments and hornblende gneiss (or metadiorite) have been intricately injected by sills and thin sheets of pink granitic material. Thus in one exposure 40 feet across, in the western part of the area, some of the metasedimentary bands, as well as some granitic bands, are fairly pure, but most of the exposure is an intimate mixture of the two rocks. Two hundred yards farther north, dark-gray gneiss is interpreted as a metadiorite-granite digestion product. The smaller area, half a mile southeast of Randsburg, shows similar banded rocks in a disrupted xenolith in quartz monzonite. The Johannesburg gneiss is quite certainly older pre-Cambrian; Hulin calls it "Archean."

Next in age is the Rand schist, so named because of its occurrence in the Rand Mountains. It comprises mainly mica-albite schist interbedded with much amphibole schist and some limestone, quartzite, and greenstone. With the possible exception of the greenstone, all members of the series are of sedimentary origin with the nearly flat-lying schistosity and bedding concordant. The Rand schist is younger than the Johannesburg gneiss (Hulin, 1925, p. 28), and it is certainly much older than the little-altered Paleozoic limestone of the near-by El Paso Mountains. Hulin calls it Archean, but the writer prefers to call it younger pre-Cambrian.

Late Mesozoic intrusives.—The Atolia quartz monzonite is so named from Atolia in the central-southern part of the area. It is extensively exposed in the southern part of the area and to a much smaller extent near Randsurg. Hulin says that the rock varies to granite and to quartz diorite. The writer has seen evidence that there is quartz diorite at least somewhat older than the quartz monzonite. Thus, in road cuts about three-fourths of a mile south of Johannesburg, much quartz diorite is cut by some quartz monzonite. A thin section of this diorite shows by volume percentages: oligoclase-andesine, 55; quartz, 18, orthoclase, 5; biotite, 9; hornblende, 6; magnetite, 1¼; and small amounts of sphene, apatite, and zircon. Chemical analysis, norm, and mode of the quartz diorite from just south of Atolia are given in Table 2 (No. 10). Also the quartz diorite "orbicles" described by Hulin (1925, p. 35-36) are probably reworked xenoliths of similar diorite in the monzonite. The writer agrees with Hulin (1925, p. 42) who says that there is little doubt about the Late Mesozoic age of the Atolia quartz monzonite. Some of the quartz diorite is probably only a little older, and very likely also Late Mesozoic.

Cenozoic dikes and volcanics.—The Miocene Rosamond series, consisting of various nonmarine sediments, with some interbedded tuffs, is widely exposed in the eastern half of the area. It is about 1000 feet thick.

Numerous large and small acidic dikes, sills, and pipes, varying from rhyolite to latite, cut the country rocks sharply. Their average composition is that of acidic quartz latite. They are generally light gray, and porphyritic, with fine-grained to glassy groundmass. They were intruded when about 200 feet of the Rosamond beds were deposited, and so they are of early Upper Miocene or Middle Miocene age. Quartz latite porphyry dikes like these occur in many parts of southern California, as for examples in the Desert Center area (Miller 1944b, p. 65–66) and in the Needles-Goffs area (Miller, 1944c, p. 121–122).

There are also many basic dikes, both basaltic and diabasic. Most of them show the same general distribution as the quartz latite dikes, which latter are intersected by them in a number of places. They cut somewhat farther into the Rosamond beds and so they are only a little younger than the quartz latite porphyry dikes. Similar basic dikes are common in many parts of southern California.

The Red Mountain andesite, so named from its occurrence in the mountain east of Randsburg, consists of varicolored andesitic lava flows, tuffs, and agglomerates. It overlies the Rosamond beds and is probably of Pliocene age. These volcanics are very widespread on Red Mountain and in the Lava Mountains.

Youngest of all the crystalline rocks is the Black Mountain basalt found in a few small areas in the north-central part of the Randsburg quadrangle. It is so named from Black Mountain 13 miles northwest of Randsburg, where it overlies Late Tertiary sediments. Its age is Late Pliocene or Early Quaternary.

EL PASO MOUNTAINS

Introduction.—This area includes the El Paso Mountains and a mountainous belt, several miles wide, adjacent to them on the north. The El Paso Mountains constitute a distinct range 20 miles long with a north-northeasterly trend and a straight steep, southern front, representing the Garlock fault scarp, which rises 1000 to 3000 feet above the alluviated valley.

Hulin (1925), in his report on the Randsburg quadrangle, includes the eastern fourth of the El Paso Mountains. Baker (1911; 1912) has described the Late Tertiary, nonmarine beds and associated volcanics in the western side of the mountains, and Miller (1926) described similar beds in Red Rock Canyon. Otherwise there are few published data on the rocks of the area. The following statements are in part based upon observations made by the writer during 6 or 7 days of field work in the area.

Paleozoic strata.—The State geologic map of 1938 shows a small area of Cambrian metasediments near the western end of the El Paso Mountains 1–2 miles east of Ricardo. It is shown in contact with a very narrow strip of Early pre-Cambrian rock on the north side. The writer has seen the metasediments which are gray, fine-grained quartzites, but nothing recognizable as pre-Cambrian rocks were observed near them. These quartzites are probably Paleozoic, but the reason for calling them Cambrian is not known to the writer.

Strata, mainly or wholly of Paleozoic age, constitute a large section of the El Paso Range 8 miles long and as wide as the range, extending from El Paso Peaks to the Canyon north of Garlock. According to Hulin (1925, p. 31–32) these sediments, with a total thickness of probably 15,000 feet, are mainly marine limestones and shales with associated cherts, sandstones, and conglomerates. Hulin (p. 33) considers them to be Paleozoic, with a few indistinct fossils suggesting Carboniferous. In the canyon north of Garlock, the writer has found what are believed to be come poorly preserved Middle or Late Paleozoic crinoidal segments in blush-gray limestone. This limestone is much like that of similar age in various parts of southern California as indicted in this paper.

Late Mesozoic intrusives.—The eastern end of the El Paso Mountains, comprising 6 or 7 square miles, is mapped by Hulin (1925, Pl. 1) as Atolia quartz monzonite which cuts the Paleozoic strata sharply. Massive, medium to moderately coarse-grained, pinkish-gray quartz monzonite, varying to granite, is the principal rock of narrower, western half of the range. Its sharp contact against the Paleozoic strata roughly follows the canyon north of Garlock. In its eastern part this monzonite has cut quartz diorite and enveloped small and large masses of it. In the canyon north of Garlock, the writer has seen a dike of the diorite in the Paleozoic limestone. This diorite, much like that near Randsburg, is probably not much older than the quartz monzonite, and both are quite certainly Late Mesozoic.

Cenozoic dikes and volcanics.—The writer has seen some basaltic dikes cutting an aplitic granite facies of the Atolia quartz monzonite in the narrows of lower Red Rock Canyon. They are probably Middle Tertiary. On the state map of 1938, an area of nonmarine Miocene beds is shown on the northwestern side of the El Paso Mountains. Hulin (1925, p. 42) says that they belong with the Rosamond series (Late Miocene). Whether or not there are associated volcanics the writer does not know.

Just north and west of the southwestern part of the mountains are the Ricardo beds (Early Pliocene) so picturesquely exposed in Red Rock Canyon. These beds are mainly arkosic and tuffaceous sediments, tuffs, and some interbedded basalt flows. Their thickness is at least several thousand feet (Miller, 1926, p. 331–335). Baker (1912, p. 123-126) describes these beds and calls them "Rosamond," but, as indicated a little beyond, the Rosamond is probably somewhat older than the Ricardo.

Hulin (1925, p. 59) says that the Black Mountain basalt is widespread in its type area on Black Mountain, north of the middle of the El Paso Mountains, where the basalt flows "occur unconformably overlying Tertiary sediments." The immediately underlying sediments seem to be Pliocene, probably Ricardo beds, which, according to the state map of 1938, rest upon the nonmarine Miocene beds which are probably Late Miocene Rosamond. The Black Mountain basalt is, therefore, either Late Pliocene or Early Quaternary.

KERNVILLE QUADRANGLE

Introduction.—The Kernville quadrangle covers more than 1000 square miles of the heart of the southern Sierra Nevada. It consists mainly of a great platform the top of which in general lies 7000–8000 feet above sea level. It has a gentle southward

downtilt, with many points in the northern part ranging between 8000 and 9956 feet. Various stream-cut canyons, 2000 to 4000 feet deep, breach the platform, the principal ones being the main Kern River Canyon on the western side, and the nearly east-west canyon of the South Fork Kern River.

There are two important papers dealing with the kinds, ages, and relations of the rocks of the quadrangle. One of these (Miller, 1931), accompanied by a geologic map, is on approximately one-third of the quadrangle, comprising an east-west area extending across its middle portion. The other is a geologic map of the whole quadrangle, accompanied by description of the rocks (Miller and Webb, 1940). Therefore, only a brief summary of the rock formations will here be presented.

Paleozoic? metasediments.—The oldest known rocks belong to the Kernville series, which is very largely phyllites, quartzites, and crystalline limestones with some interbedded metavolcanics (andesitic flows and pyroclastics). These reach a thickness of probably not less than 15,000 feet. Members of the series are widespread in small and large areas in all but the central and southeastern parts of the quadrangle. The age of the Kernville series is not certain, but it is probably Carboniferous, perhaps the equivalent of the Calaveras of the middle-western Sierra Nevada.

Mesozoic or Late Paleozoic diorites.—Next in order of age is the Summit gabbro-diorite which varies from olivine gabbro to hornblende gabbro or diorite. It occurs in various small and large areas in the southwestern, middle-eastern, and northeastern parts of the quadrangle. It cuts the Kernville series. Chemical analyses, norms, and modes of two specimens of the Summit gabbro are given in Table 2 (Nos. 25, 24).

The Sacatar quartz diorite varies from hornblende diorite, through quartz diorite with considerable potash feldspar, almost to a granodiorite. It occurs mainly in the northeastern part of the quadrangle and to a small extent in the southwestern part. It cuts both the Kernville series and the Summit gabbro, but it is close genetically to the latter; contacts between the two are often gradational. Some facies of the Sacatar are difficult to distinguish from dioritic facies of the Isabella granodiorite. Both the Summit gabbro and the Sacatar quartz diorite are much like earlier members of the Late Mesozoic plutonic sequence of many parts of southern California as indicated in this paper. Possibly, however, part or all of the diorite is of Late Paleozoic age, which may be true of similar rock in the Mother Lode region (Knopf, 1929, p. 19).

Late Mesozoic granodiorite.—The Isabella granodiorite varying to quartz diorite, and through quartz monzonite to granite, occupies more of the quadrangle than all other rock units combined. It sends off many pegmatite and aplite dikes. The Isabella cuts all previously mentioned rocks of the quadrangle, but there is no positive evidence that it is much younger than the Sacatar quartz diorite, since some facies of the two are very similar. It is no doubt part of the great Sierra Nevada batholith of Late Mesozoic age. Chemical analysis, norm, and mode of the Isabella granodiorite are given in Table 2 (No. 23). In common with similar relationships in various parts of southern California, as indicated in this paper especially in the Peninsular Mountains, the writer believes that the best interpretation is that the Summit gabbro-diorite, Sacatar quartz diorite, and Isabella granodiorite are members of a Late Mesozoic plutonic sequence ranging from gabbro to granite.

Late Cenozoic volcanics.—About a dozen small areas of volcanic rocks, mainly olivine basalts and olivine andesites, occur in the northern half of the quadrangle. They are quite certainly of Late Cenozoic age like similar lavas farther north.

TEHACHAPI-ROSAMOND AREA

Introduction.—This area includes a small part of the southern Sierra Nevada, extending from the vicinity of Tehachapi east and southeast to the foot of the mountains, and a small part of the Mohave Desert west of the railroad which connects Mojave and Rosamond. Altitudes in the mountains range between 4000 and 6000 feet, while the alluviated desert floor, about 3000 feet above sea level, has various hills and small mountains rising to a maximum of 1000 feet above it.

No important published account of the crystalline rocks of the northern part of the area is available, but the southern part has been reported on and geologically mapped by Simpson (1934). Hershey (1902, b) named and described the Rosamond series at its type locality. The following notes on the northern part are based upon 6 or 7 days of reconnaissance work by the writer.

Paleozoic? metasediments.—Oldest of the known rocks of the area are metasediments with some associated metavolcanics. They include the Bean Canyon series of Simpson (1934, p. 381–384) who has mapped and described several occurrences of the series in the northwestern part of the Elizabeth Lake quadrangle. He says (p. 381–382) that the "Bean Canyon series consists of schist, slate, and crystalline limestone" representing "the metamorphic equivalent of a series of shales, sandstones, limestones, tuffs, and lava-flows, waterlaid sediments for the most part." A stratigraphic section in Bean Canyon shows a thickness of 3800 feet.

In lower Oak Creek Canyon, and south of it for several miles, the writer has seen fine exposures of the Bean Canyon series, including much crystalline limestone. The steep-dipping beds were cut first by diorite and then by granodiorite, both as small and large sills. Some interbedded metavolcanic material was seen by the road 1½ miles south of Cameron Valley School, and, ¾ mile west of that locality, schistose beds are somewhat granite-injected.

Observations by the writer show that, in the big limestone quarry and vicinity 4 miles south of Tehachapi, there are great exposures of steep-dipping, well-bedded, variable crystalline limestones with many intercalated beds of gray, usually fine-grained, quartzitic, biotitic, and amphibolitic schists which latter are often somewhat injected *lit-par-lit* by granitic material.

The hills 1–2 miles northwest and north of Monolith consist almost wholly of crystalline limestone with more or less interbedded schist and quartzite. The Monolith Cement quarries are in this limestone.

The metasediments from all four areas just described are tentatively correlated with the Kernville series of the Kernville quadrangle, which are probably Late Paleozoic. Simpson (1934, p. 383) says that the Bean Canyon series is probably the equivalent of part of the Kernville series, but he favors an early Mesozoic age for it. From Brights (or Brite's) Valley southwest of Tehachapi, Goodyear (1888b, p. 310) reported some "indistinct remnants of what were probably crinoidea" in marble which

Simpson (p. 383) thinks may correlate with that of his Bean Canyon series. The metasediments are certainly older than the extensive Late Mesozoic quartz monzonite of the area.

Mesozoic or Late Paleozoic diorite.—The principal rocks for a mile or two either side of Cache Creek Canyon, between Cameron and Warren, comprise a plutonic complex where much quartz-hornblende diorite has been cut to pieces and exists as small and large inclusions in massive, medium-grained, pink quartz monzonite. Some of the inclusions are large enough to be mapped. The diorite varies from massive to more or less foliated, the latter structure usually being best developed in the small bodies and in border portions of the large bodies. Highly foliated portions are locally injected almost *lit-par-lit* by monzonitic material, as for example along the highway just northwest of Cameron. The diorite is megascopically and microscopically much like the Mesozoic or Late Paleozoic Sacatar quartz diorite of the Kernville quadrangle, and it is no doubt correlative with it. It is probably Late Mesozoic. A thin section of a finer medium-grained, massive, equigranular facies of the diorite from a mixed-rock area 8 miles north-northeast of Mojave shows by volume percentages: quartz, 10; acidic andesine, 68; hornblende, 15; biotite, 5; magnetite, ¾; and a little epidote and apatite. Simpson (1934, p. 388) says that "hornblende-quartz diorite occupies a large area in the Tehachapi Mountains north of the Oak Creek Canyon fault."

Late Mesozoic quartz monzonite.—Quartz monzonite, varying to granodiorite, is widely exposed in the mountains of the Tehachapi-Rosamond area. It is doubtless part of the great Late Mesozoic, Sierra Nevada batholith, including the Isabella granodiorite of the Kernville quadrangle. A thin section of the typical, massive rock from 7½ miles north of Mojave shows by volume percentages: quartz, 35; orthoclase, 17; microcline, 10; oligoclase, 29; biotite, 4; magnetite, 4; sphene, 4; and small amounts of sericite, epidote, and apatite. In the desert region, a fairly large body of the quartz monzonite occurs north and northeast of Rosamond as mapped by Simpson (1934, Pl. 5).

Late Tertiary volcanics.—The type area of the Rosamond series is in the hills northeast to northwest of Rosamond. It was first described by Hershey (1902b). It has been mapped by Simpson (1934, Pl. 5) who says that it consists largely of coarse conglomerates, sandstones, siltstones, pumiceous sandstones, tuffs, lava flows, and agglomerates. All sediments are nonmarine. The lavas, including dacite, rhyolite, and basalt, are in the lower half of the series which is several thousand feet thick. The series is believed to be Middle or Late Miocene (Simpson, 1934, p. 400–401). Soledad Mountain, 4–6 miles south of Mojave, is made up largely of dacite flows. There is a large area of Miocene nonmarine sediments with associated volcanics east and northeast of Monolith, some of the volcanics being well exposed just north of Eric station. These may belong with the Rosamond.

GRAPEVINE-GORMAN AREA

Introduction.—This area lies between Gorman in the northwestern corner of Los Angeles County and Grapevine in southwestern Kern County. It is crossed by

U. S. Highway 99 (Ridge Route). It is a rugged, mountanious country with altitudes ranging from 2000 feet to more than 5000 feet in that part of the area studied by the writer. The San Andreas fault cuts through the southern part of the area.

The only published geologic map of this area is part of the state map of 1938 on which the crystalline rocks are all grouped together as "undivided granitic rocks." Field observations by the writer in about 15 square miles of the area indicate several important kinds and ages of crystalline rocks.

Igneous rocks.—Beginning about a mile south of Grapevine, near the mouth of Grapevine Canyon, a gray, medium-grained, massive to moderately foliated quartz diorite with basic schlieren is solidly exposed for a mile south in the canyon walls. This diorite is probably correlative with the Late Mesozoic Wilson diorite of the western San Gabriel Mountains. For the next 3 miles south, the canyon sides consist of a complex of metadiorite (or amphibolite) and pinkish granite often crudely banded and cut to pieces sharply by the diorite. From a little north to 1 mile south of Old Fort Tejon, the highway crosses a belt of the complex. This complex probably belongs with the Early pre-Cambrian San Grabriel complex of the San Gabriel Mountains. Between 1 and 2 miles southeast of Old Fort Tejon (east of the highway) there is more of the massive to moderately foliated, gray quartz diorite cut sharply by some small dikes of granodiorite probably to be classed with the Late Mesozoic Lowe granodiorite of the San Gabriel Mountains.

The sides of lower Cuddy Canyon, as far west as Frazier Park, seem to consist largely of the old granite-metadiorite complex much like that at Old Fort Tejon. It is cut sharply by large and small masses of granodiorite or quartz monzonite much like the Lowe granodiorite of the San Grabriel Mountains.

Frazier Mountain, which lies just south of lower Cuddy Canyon, is, according to Buwalda, Gazin, and Sutherland (1930, p. 146) "made of pre-Cretaceous crystalline rocks, mainly gneiss, schist, and intrusives." The writer's meager observations suggest that most of these rocks comprise a complex to be classed with that around Old Fort Tejon.

A similar complex of metadiorite granite was noted west of the San Gabriel fault 5 or 6 miles south-southwest of Gorman.

Paleozoic? metasediments.—At Lebec there is a fine outcrop of well-bedded, moderately metamorphosed, crystalline limestone, mostly bluish gray, but with some white beds. It looks much like limestones which, in various parts of southern California, are more or less definitely known to be Late Paleozoic. From 1 mile north of Tejon Pass to the vicinity of Gorman, there is a belt of similar crystalline limestone, several miles in length, with considerable interbedded metavolcanic material. Between 1 and 2 miles southwest of Lebec, the rock is well-bedded, gray, impure quartzite, with some associated quartz-mica schist, cut sharply by small bodies of massive to moderately foliated granite, probably Late Mesozoic. The limestone, with associated volcanics, and the quartzite are probably parts of a single formation or series which is much younger than the complex near Old Fort Tejon. It is, in all important respects, much like the Kernville series of the southern Sierra Nevada and probably of the same age (Late Paleozoic?).

LAKE HUGHES-ACTON AREA

Introduction.—This area of nearly 300 square miles lies adjacent to the San Gabriel Mountains on the northwest. Most of it covers the southwestern fourth of the Elizabeth Lake quadrangle. It extends a few miles into the southeastern part of the Tejon quadrangle to Elizabeth Lake Canyon, and a few miles ito the northwestern part of the Tujunga quadrangle. It is a mountainous country with altitudes throughout the area usually ranging from 2000 feet to over 5000 feet. The San Andreas fault cuts lengthwise through the northeastern part of the area for many miles. Sierra Pelona ridge, a prominent feature of the landscape, is more than 20 miles long and 4–5 miles wide.

Many years ago Hershey (1902a, p. 274–279) named and described the Pelona schist series of Sierra Pelona ridge. Simpson (1934), in his report on the Elizabeth Lake quadrangle, described and mapped the rocks of most of the area. Webb (1932), in an unpublished thesis, has mapped and described an eastern section of the area, and he has published a brief account of the quartz syenite found there (Webb, 1938). The writer has visited all parts of the area.

Pre-Cambrian rocks.—Except for Portal Ridge and Jupiter Mountain, Simpson (1934, Pl. 5) has mapped all crystalline rocks north of the Bouquet Canyon fault, in the Elizabeth Lake quadrangle, as Late Jurassic "quartz monzonite and other intrusives", and Jupiter Mountain is mapped as Late Jurassic hornblende diorite and granodiorite. The writer, however, believes that all or nearly all these crystallines constitute a complex confidently classed with the San Gabriel complex (Miller, 1934, p. 49–57) of the near-by San Gabriel Mountains, and there regarded as Early pre-Cambrian. The complex is a more or less variable and intricate mixture of dioritic and metadioritic rocks cut to pieces, granitized, and often injected *lit-par-lit* by much granitic material, often with resultant crudely banded gneisses. Some associated schists may be metasedimentary. Excellent exposures of such rocks occur also in Elizabeth Lake Canyon for several miles north of the Bouquet Canyon (or Clearwater) fault. Simpson (1934, p. 388–389) mentions occurrences of similar gneisses, but he thinks that they may represent Pelona schist, injected and migmatized by Late Mesozoic granitic material.

A narrow belt of a dioritic facies of anorthosite, about 2 miles long, occurs 2–2½ miles west to west-northwest of Vincent. It represents a small, outlying mass of the large body of anorthosite of the near-by San Gabriel Mountains.

Another ancient and extensively developed formation is the Pelona schist, so named and described by Hershey (1902a, p. 274–277) from its occurrence in Sierra Pelona Ridge. Both Sierra Pelona Ridge and Portal Ridge consist of this formation. According to Simpson (1934, p. 378) "The Pelona schist series is a group of metamorphosed sedimentary rocks, lavas, and tuffs, consisting for the most part of greenstone schist, amphibole schist, mica schist, quartzite, and (crystalline) limestone, whose total exposed thickness is estimated to be more than 7,500 feet." Mica schists of sedimentary origin are the most abundant rocks. The Pelona schist is almost exactly like the Rand schist of the Randsburg area, the latter being regarded as Archean by Hulin (1925, p. 29–31). The writer agrees with Simpson and Hulin in assigning a pre-Cambrian age to the Pelona schist. It is, however, younger than the plutonics

of the near-by San Gabriel complex because they nowhere penetrate the schist. Wherever the Pelona schist and the complex come together, the contacts are, as far as known, faults. It may be older pre-Cambrian, but the writer tentatively calls it younger pre-Cambrian.

Late Mesozoic intrusives.—A gray to dark-gray, medium-grained, massive to crudely gneissoid diorite extends, in almost continuous exposures, for 4 miles down Elizabeth Lake Canyon from 1 mile west of the eastern boundary of the Tejon quadrangle. Its full east-west extent is not known. It has small, basic schlieren; it contains large and small xenoliths of the San Gabriel complex; and it cuts the pre-Cambrian complex in the canyon. A thin section of the diorite shows by volume percentages: andesine, 56; hornblende, 20; biotite, 20; magnetite, 3; apatite, $\frac{3}{4}$; and traces of sphene and zircon. By the road in Elizabeth Lake Canyon, 4 miles southwest of Lake Hughes, a hornblende-rich diorite has been cut by granite and pegmatitic granite into numerous angular blocks of varying size up to several feet in diameter. These blocks have been slightly injected with granitic material. Similar xenoliths of diorite (Late Mesozoic) have been observed by the writer in various parts of San Diego County. These diorites are tentatively correlated with basic facies of the Late Mesozoic Wilson diorite of the San Gabriel Mountains.

A group of plutonic rocks, presumably Late Mesozoic, is extensively exposed in a belt several miles wide, south of Sierra Pelona ridge. Most of these rocks are represented on Simpson's map (1934), and others on the writer's map (1934). The rocks include quartz diorite, granodiorite, quartz monzonite, aplitic quartz monzonite, quartz syenite, and granite. Pegmatite and aplite offshoots of these rocks are common. They all seem to be closely related genetically. One important unit has been called the Parker quartz diorite (Miller, 1934, p. 37–39). It is well shown in the general vicinity of Acton and Vincent. One area of quartz syenite, several miles long, has been mapped by Simpson, but 3 small areas mapped by the writer, several miles north of Acton, extend some distance into areas mapped as quartz diorite by Simpson. Several areas are rather confidently classed with the Lowe granodiorite (or quartz monzonite), as for example 1 mile south and east of Vincent, and a belt several miles long bordering and cutting the Pelona schist north of Texas Canyon. Simpson's area of "monzonite aplite" is also regarded as a facies of the Lowe granodiorite. The age relations of various members of this group of plutonic rocks has been discussed (Miller, 1934, p. 38–41). The Parker quartz diorite and the quartz syenite are at least somewhat older than the Lowe granodiorite because the latter sends aplite, granite, and pegmatite dikes into them. Both the syenite and the diorite may be intermediate in age between the Wilson diorite and the Lowe granodiorite.

Many sharply defined, lamprophyric dikes, with a general composition of gabbrodiorite, cut both the Parker diorite and the quartz syenite in the southeastern part of the area (Miller, 1934, p. 68–69). They are younger than the Late Mesozoic aplite dikes in the diorite and they do not cut the Middle or Late Miocene Escondido series to be described. They may be Early or Middle Tertiary, but possibly they and the Late Mesozoic aplite dikes are complementary dikes.

Tertiary dikes and volcanics.—Some small, sharply defined, basic (diabasic) dikes

occur in the southeastern part of the area. They are like those of the near-by San Gabriel Mountains (Miller, 1934, p. 69–70) and are believed to be Middle Miocene like the basaltic intrusives of the Santa Monica Mountains.

In the southern part of the area, between Pelona Ridge and Soledad Canyon, the Escondido series, so named by Hershey (1902b, p. 350–355) from its occurrence in Escondido Canyon, is widely exposed. Its distribution is shown on three maps; Kew (1924, Pl. 1) mapped it as Sespe?; Miller (1934) mapped it as a sedimentary-volcanic formation; and Simpson (1934, Pl. 5) mapped it as Escondido series. It is a succession of volcanic rocks and continental sediments, the former being mainly basaltic and andesitic lava flows with considerable associated agglomerate. The volcanics are exposed in various areas and range in size to several square miles. In Escondido Canyon, according to Kew (1924, p. 39), the series is 8400 feet thick, of which about 3700 feet consists of lava flows, and the rest of conglomerates, sandstones, and shales. It there lies unconformably under the Mint Canyon formation (Late Miocene). Kew (p. 39) tentatively correlated the Escondido with the Sespe (Oligocene or Early Miocene). Both the writer (Miller, 1934, p. 66) and Simpson (1934, p. 395) assign it to the Middle Miocene.

CHEMICAL ANALYSES, NORMS, AND PETROGRAPHY OF THE INTRUSIVE ROCKS

CHEMICAL ANALYSES

Tables 1, 2, and 3 show chemical analyses, norms, and modes of 29 igneous rocks. All analyses were made in the Rock Analysis Laboratory at the University of Minnesota. They represent carefully selected specimens of the most important kinds and ages of intrusive rocks in southern California. The accompanying map (Pl. 1) indicates the localities from which the specimens were collected. Norms have been calculated according to the C.I.P.W. system. The modes are given in approximate weight percentages in order that direct comparisons with the norms may be made. Because of the difficulty of finding unaltered and uncontaminated specimens from reasonably large areas, only four analyses of the older pre-Cambrian plutonic rocks have been made. These four, however, give a fairly good idea of the purer facies of these ancient rocks.

PETROGRAPHY

Older pre-Cambrian plutonics.—Nos. 21 and 19 of Table 1 are fairly representative of the oldest known intrusives in southern California. No. 21 is hornblende-rich Rubio diorite which is widely distributed in the San Gabriel Mountains (Miller, 1934, p. 7–11), and No. 19 is Gold Park gabbro from the Twenty-nine Palms region (Miller, 1938, p. 419–421). The analyzed specimens are dark gray to nearly black, massive, and medium-grained to moderately coarse-grained. They are from mapped bodies whose border portions are usually well foliated, locally even schistose. In the field these rocks show pronounced local variations as is often true of gabbro and basic diorite. In No. 21 the texture is allotriomorphic, inequigranular, and the labradorite is sodic. CO_2 was omitted from calculation of the norm. In No. 19, the texture is diabasic; nearly equigranular; the labradorite is calcic; the biotite is all chloritized; and there is considerable deuteric epidote.

Nos. 2 and 11 of Table 1 are good examples of the oldest known, uncontaminated granitic rocks of southern California. In many areas these rocks have cut to pieces, *lit-par-lit* injected, and variably digested still older pre-Cambrain metasediments and basic igneous rocks. Mappable areas of the purer granites are uncommon. No. 2 (Echo granite) is widespread in the San Gabriel Mountains, mostly as part of the San Gabriel complex (Miller, 1934, p. 12–15). It varies to quartz monzonite as is true of the analyzed rock which is pinkish gray, medium-grained, and distinctly gneissoid. In thin section it is allotriomorphic, inequigranular, and it shows considerable protoclastic granulation of quartz and feldspars, with suture texture between the larger mineral grains. The Berdoo granite (No. 11) is associated with the Chuckwalla complex in the Little San Bernardino Mountains. It is pinkish gray, moderately coarse-grained, and distinctly foliated. Microscopically it is allotriomorphic, inequigranular, and shows much protoclastic granulation. The oligoclase is calcic, and small scattered grains of myrmekite indicate deuteric action.

Late Mesozoic plutonics.—Table 2 shows 23 analyses, norms, and modes of specimens carefully selected to represent the Late Mesozoic plutonic series in southern California. This series, varying from olivine gabbro and norite through quartz diorite, granodiorite, and quartz monzonite to granite, is widespread in the form of numerous large and small plutons. Quartz diorite, granodiorite, and quartz monzonite are most common.

The first three analyses in Table 2 represent gabbroic facies of the plutonic series. The Viejas gabbro (No. 5) is important in southern San Diego County (Miller, 1935a, 123–125). Analyses, norms and modes of the San Marcos gabbro of northwestern San Diego County are given by F. S. Miller (1937, p. 1412). This gabbro is confidently regarded as a correlative of the Viejas gabbro. Megascopically, the analyzed Viejas gabbro is dark gray, massive, fine-grained to moderately medium-grained. In thin section it is inequigranular and allotriomorphic.

Two analyses of the Summit gabbro of the Kernville quadrangle (Miller and Webb, 1940, p. 353–354) are given in Table 2. One of these (No. 25) is a dark-gray, massive, fine-grained, equigranular olivine gabbro containing antigorite. In thin section it shows a crude diabasic texture. The plagioclase is fresh, but the hornblende, augite, and olivine are much altered. The other specimen (No. 24) is gray, massive, and medium-grained. In thin section it is subequigranular, and allotriomorphic with a normal plutonic texture. It is hornblende-rich. As mentioned, the Summit gabbro may be Late Paleozoic but is probably Late Mesozoic.

Analyses of nine specimens of Late Mesozoic quartz diorite are given in Table 2. No. 27 represents a dioritic facies of the San Jacinto batholith. It is light gray, faintly gneissoid, medium-grained, subequigranular, and hypidiomorphic usually with subhedral to euhedral biotites and hornblendes. It is much like the La Posta quartz diorite of San Diego County (Table 2, No. 6).

The Perris quartz diorite (No. 13) is extensively developed in the Perris-Riverside area (Dudley, 1935, p. 501). It is gray, coarser medium-grained, distinctly gneissoid, subequigranular, allotriomorphic, and contains small schlieren.

No. 1 is typical of the Wilson quartz diorite in the San Gabriel Mountains (Miller, 1934, p. 30–36). It is gray, medium-grained, faintly gneissoid, equigranular, and allotriomorphic. There is a little protoclastic granulation of the feldspar and quartz.

TABLE 1.—*Chemical analyses, norms, and modes of older pre-Cambrian plutonic rocks*

	21	19	2	11
ANALYSES				
SiO_2	46.61	46.73	75.39	73.91
Al_2O_3	13.94	21.33	13.70	14.06
Fe_2O_3	3.20	3.97	.29	.52
FeO	7.18	4.81	.50	.73
MgO	10.71	4.26	.23	.37
CaO	9.80	13.34	1.04	1.51
Na_2O	2.59	2.70	3.44	2.98
K_2O	1.22	.26	5.01	5.54
H_2O^+	1.68	.69	.16	.10
H_2O^-	.07	.06	.03	.03
CO_2	.28			
TiO_2	2.30	1.66	.12	.17
ZrO_2		.01	.01	.02
P_2O_5	.16	.09	.03	.06
MnO	.10	.09	.02	.02
BaO			.09	
	99.84	100.00	100.06	100.02
NORMS				
Q			33.54	31.32
or	7.23	1.67	29.47	32.80
ab	20.44	23.05	28.82	25.15
an	22.52	45.04	5.56	7.51
ne	.85			
C			.61	.41
di	20.14	16.15		
hy			1.13	1.56
ol	17.21	4.17		
mt	4.64	5.80	.46	.70
il	4.41	3.19	.15	.30
ap	.34	.34		
	97.78	99.41	99.74	99.75
MODES (Weight percentages)				
Quartz			34.0	32.0
Orthoclase			7.0	11.0
Microcline			23.0	18.0
Microperthite				7.0
Plagioclase	21.0	70.0	34.0	25.0
Kind of plagioclase	Lab.	Lab.	Ol.	Ol.
Biotite	9.0		1.4	3.0
Hornblende	66.0	1.8		
Augite		17.0		
Chlorite		4.3		
Magnetite	1.5	5.0	0.4	0.7

TABLE 1—*Continued*

	21	19	2	11
MODES (Weight percentages)—*Continued*				
Pyrite		0.4		
Myrmekite				2.9
Sphene	1.5		0.2	
Epidote		1.2		
Apatite	0.2	0.2	0.1	0.2
Zircon	0.1		0.2	0.1
Calcite (Secondary)	0.2			
Allanite	0.7			
	100.2	99.9	100.3	99.9

21. Rubio diorite; lower Rubio Canyon, middle-southern San Gabriel Mountains. R. W. Perlich, analyst.
19. Gold Park gabbro; lower Gold Park Canyon, 4 miles south-southeast of Twenty-nine Palms. R. W. Perlich analyst.
2. Echo granite; mouth of Arroyo Seco Canyon, middle-southern San Gabriel Mountains. A. Willman, analyst.
11. Berdoo granite; lower Berdoo Canyon, Little San Bernardino Mountains. R. B. Ellestad, analyst.

No. 6 is typical of the La Posta quartz diorite in southeastern San Diego County (Miller, 1935a, p. 129–131). It is very light gray, massive, medium-grained to moderately coarse-grained, and hypiodiomorphic, with irregularly scattered hornblendes and biotites reaching dimensions of 2–10 millimeters.

The Alpine quartz diorite of southwestern San Diego County (Miller, 1935a, p. 126) is well represented by No. 4, Table 2. It is gray, massive, medium-grained, and granitoid.

No. 12 represents an extensively developed quartz diorite in the northwestern part of the Santa Rosa Mountains. It is gray, faintly gneissoid, medium-grained, equigranular, and allotriomorphic. The CO_2 was omitted from calculation of the norm.

No. 15 is typical of the Fargo Canyon quartz diorite (Miller, 1944a, p. 59–60) in Fargo Canyon in the Little San Bernardino Mountains. It is gray, massive, medium-grained, and granitoid.

The Atolia quartz diorite (No. 10) is from the type locality in the Randsburg area (Hulin, 1925, p. 33–34). It is light gray, faintly foliated, equigranular, and allotriomorphic. The CO_2 was omitted from calculation of the norm.

All eight quartz diorites just described from widely separated parts of southern California are very similar in regard to chemical composition, norm, mode, and texture. No. 17, Table 2, which probably belongs in the same age category, is distinctly more basic. It is gray, massive, medium-grained, and granitoid with the feldspar considerably altered deuterically. All nine of them may be called tonalites because biotite is always an important constituent. Analyses of three tonalites from northwestern San Diego County have been published. They also belong to the Late Mesozoic plutonic series. Two are analyses of the Bonsall tonalite by Hurlbut (1935, p. 613), one of which, typical of that rock, is much like several of the dioritic analyses listed in Table 2. The third published analysis is of the Green Valley tonalite by F. S. Miller (1937, p. 1412). It is much like that of the Alpine quartz diorite (Table 2, No. 4).

TABLE 2.—*Chemical analyses, norms, and modes of late Mesozoic plutonic rocks*

	5	25	24	27	13	1	6	4	12	15	10	17	28	23	3	22	8	18	7	14	20	9	16
ANALYSES																							
SiO_2	44.66	46.82	45.67	64.84	62.93	60.75	67.50	64.88	62.76	62.13	62.03	51.31	74.63	71.51	68.54	72.17	69.14	68.27	77.25	66.38	77.37	75.02	74.48
Al_2O_3	22.85	20.81	18.97	16.93	15.98	16.79	15.88	15.31	15.96	16.87	17.31	21.00	14.49	14.59	16.97	14.02	15.30	16.29	12.71	16.33	12.36	13.29	13.66
Fe_2O_3	3.88	.49	1.54	.80	1.02	2.26	.49	1.45	1.08	1.88	1.77	3.83	.29	.78	1.01	.41	1.07	.92	.29	1.74	.68	.49	.57
FeO	6.44	5.52	8.20	3.27	4.84	3.44	2.79	3.83	3.89	3.29	2.83	3.76	.35	1.92	.73	2.40	1.69	1.54	1.00	1.71	.40	.34	.73
MgO	5.22	8.85	7.05	1.49	2.59	2.94	1.57	2.35	2.92	2.45	1.95	3.39	.20	.72	.29	.91	1.03	.96	.22	.75	.09	.17	.34
CaO	14.56	14.41	12.56	4.89	5.59	5.25	4.25	5.16	5.21	4.99	5.18	10.81	1.00	1.85	2.70	2.69	2.95	3.09	.84	1.96	.20	.88	.96
Na_2O	1.08	1.24	1.94	3.76	3.60	3.75	3.93	3.25	3.19	3.62	3.97	2.41	4.25	3.83	4.70	3.46	3.76	4.46	4.24	4.37	4.24	3.46	3.48
K_2O	.07	.19	.53	2.26	1.59	2.75	1.98	2.11	2.71	2.62	1.98	1.15	4.13	3.96	4.18	3.17	3.52	3.06	2.95	5.12	4.37	5.73	4.97
H_2O+	.24	1.09	1.52	.39	.57	.65	.48	.50	.59	.64	.93	1.08	.18	.28	.19	.23	.32	.35	.14	.45		.18	.31
H_2O-	.08	.04	.05	.07	.04	.03	.01	.05	.04	.03	.06	.07	.05	.04	.01	.02	.09	.12	.02	.13	.02	.06	.09
CO_2	.03						.04		.21		.33						.12			.14		.11	
TiO_2	.96	.35	1.48	.77	.86	.76	.64	.74	.94	.86	.99	.77	.08	.31	.20	.38	.55	.49	.14	.37	.12	.15	.24
ZrO_2				.02	.04	.02	.01	.01	.02	.03	.03	.01	.01	.03	.01	.02	.01	.02	.01	.05	.02	.03	.02
P_2O_5	trace	.04	.18	.19	.16	.25	.17	.14	.22	.26	.32	.15	.03	.08	.06	.09	.18	.18	.03	.14	.01	.02	.06
MnO	.11	.11	.17	.06	.10	.08	.06	.09	.07	.08	.06	.12	.02	.07	.09	.06	.06	.04	.03	.10	.09	.01	.04
BaO						.11									.32								
	100.18	99.96	99.86	99.74	99.91	99.83	99.80	99.87	99.81	99.75	99.74	99.86	99.71	99.97	100.00	100.03	99.79	99.79	99.87	99.74	99.97	99.94	99.95
NORMS																							
Q				20.22	18.24	13.08	24.42	22.68	17.10	16.32	17.22	5.88	31.32	28.32	18.60	31.44	25.62	22.26	38.82	16.20	35.28	30.90	32.52
or	.56	1.11	2.78	13.34	9.45	16.12	11.68	12.23	16.12	15.57	11.68	6.67	24.46	23.35	25.02	18.90	20.57	18.35	17.24	30.02	26.13	33.92	29.47
ab	8.91	10.48	16.24	31.96	30.39	31.44	33.01	27.25	27.25	30.39	33.54	20.44	36.15	32.49	39.82	29.34	31.96	37.73	35.63	36.68	35.63	29.34	29.34
an	57.27	47.82	41.70	22.52	22.80	21.13	20.29	21.13	21.13	22.24	23.63	43.09	5.00	8.34	12.79	12.51	13.90	14.46	4.17	8.90	1.11	3.61	4.73
C													1.12	.92		.20	.20	.31	1.12	.41	.20		.82
di	12.06	16.74	16.07	.93	3.46	2.91		2.97	3.16	.68	.43	7.97			.89							.75	
hy	11.56	6.02	1.43	7.33	11.51	9.17	7.73	9.09	10.52	8.94	6.81	7.08	.76	4.18	.63	5.73	4.05	4.07	2.05	2.82	.46		1.20
ol	1.90	15.74	14.49																				
mt	5.57	.70	2.32	1.16	.91	3.25	.70	2.09	1.62	2.78	2.55	5.57	.46	1.16	1.39	.70	1.62	1.39	.46	2.55	.93	.70	.93
il	1.82	.61	2.89	1.52	1.67	1.52	1.22	1.37	1.82	1.67	1.98	1.52	.15	.61	.46	.30	1.02	.91	.15	.76	.15	.30	.46
ap			.34	.33	.34	.67	.34	.34	.34	.67	.67	.34		.34		.34	.34	.34		.34			
	99.65	99.22	98.26	99.31	98.77	99.29	99.39	99.15	99.06	99.26	98.51	98.56	99.42	99.71	99.60	99.46	99.28	99.82	99.64	98.68	99.89	99.52	99.47

Quartz				25.0	23.0	18.0	27.0	24.0	22.0	20.0	21.0	7.0	33.0	30.0	19.0	35.0	28.0	28.0	39.0	18.0	38.0	34.0	32.0
Orthoclase				8.0	4.4	11.0	7.0	6.0	4.0	11.0	2.0				12.0	10.0	14.0		4.3			30.0	
Microcline									8.0														
Albite												3.0	34.0	31.0	12.0		5.0	41.0	42.0	43.0			
Oligoclase																							
Andesine																							
Labradorite																							
Anorthite																							
Nepheline																							
Leucite																							
Kaliophilite																							
Acmite																							
Sodium metasilicate																							
Diopside																							
Hypersthene																							
Olivine																							
Magnetite																							
Ilmenite																							
Hematite																							
Apatite																							
Calcite																							
Zircon																							
Rutile																							
Pyrite																							
Water																							

Quartz				25.0	23.0	18.0	27.0	24.0	22.0	20.0	21.0	7.0	33.0	30.0	19.0	35.0	28.0	28.0	36.0	10.0	38.0	41.0	32.0
Orthoclase				8.0	4.4	11.0	7.0	6.0	4.0	11.0	2.0				12.0	16.0	14.0		4.5			30.0	
Microcline									8.0			2.0	24.0	21.0	13.0		5.0	16.0	12.0	28.0			
Microperthite														4.0							62.0	13.0	49.0
Plagioclase	66.0	54.0	30.0	53.0	53.0	50.0	53.0	47.0	49.0	53.0	53.0	60.0	41.0	39.0	52.0	40.0	45.0	52.0	39.0	46.0		21.0	15.0
Kind of Plag	Byt.	Byt.	Lab.	And.	And.	And.	And.	And.	And.	And.	And.	Lab.	Ol.	Ol.	Ol.	Ol.	Ol.	Ol.	Ol.	Ol.		Ol.	Ol.
Biotite		2.0	1.7	9.0	9.0	8.0	8.0	11.0	8.0	9.0	18.0	6.0	.6	4.2		5.0	5.0	4.1	3.3	3.9	.7	2.2	1.4
Hornblende	4.0	22.0	66.0	2.5	9.0	9.0	3.5	6.0	7.0	5.0	.5	17.0		.4	1.5	2.4			1.5		1.5		
Augite		8.0						5.0			.4					.4							
Olivine	21.0	3.9																					
Diallage	8.0																						
Chlorite											.3			.3			.7						.2
Magnetite	1.3	.9	1.5	1.1	.5	1.5	.5	.7	.2	1.2	1.1	2.5	.3	.7	.9	.5	1.0	1.0	.2	1.6	.5	.5	.9
Sphene				.6	.8	.7	.5		.8	.6	1.0	.7			.7	.4	.7	.6	.2	.5	.2	.2	.6
Myrmekite						.7												.3					
Epidote			.4	.2		.3			.2		2.0	3.2	.2	.1	.7	.2				.4			.2
Apatite			.2	.3	.2	.5	.2	.3	.2	.3	.3	.2	.1	.1	.1	.2	.2	.2	.1	.2			.2
Zircon				.1	.1	.1		.1	.1	.1	.1	.1	.1	.1		.1	.1	.2	.1	.2	.1	.1	.1
Allanite														.2				.2		.2		.2	.2
Muscovite													.5										
Sericite												1.0	.3					.5					.1
Calcite									.2		.4						.1						
Antigorite		9.0																					
	100.3	99.8	99.8	99.8	100.0	99.8	99.7	100.1	99.7	100.2	100.1	99.7	100.1	100.1	99.9	100.2	99.8	100.1	99.9	100.0	100.0	100.2	99.9

5. Viejas gabbro; south base of Viejas Mountains, southern San Diego County. L. C. Armstrong, analyst.

25. Summit olivine gabbro; 2 miles south-southwest of Kernville. G. Kahan, analyst.

24. Summit hornblende gabbro; by the road 3 miles west-southwest of Kernville. G. Kahan, analyst.

27. Quartz diorite; Chino Canyon, 3½ miles northwest of Palm Springs. R. B. Ellestad, analyst.

13. Perris quartz diorite; Box Spring grade, 3½ miles east-southeast of Riverside. R. B. Ellestad, analyst.

1. Wilson quartz diorite; top of Mt. Wilson, middle-southern San Gabriel Mountains. A. Willman, analyst.

6. La Posta quartz diorite; by the main road in La Posta Valley, southeastern San Diego County. L. C. Armstrong, analyst.

4. Alpine quartz diorite; near Alpine, middle-southern San Diego County. L. C. Armstrong, analyst.

12. Quartz diorite; by the main road near middle-western border of Indio quadrangle, northwestern Santa Rosa Mountains. R. B. Ellestad, analyst.

15. Fargo Canyon quartz diorite; 2 miles up Fargo Canyon, 9 miles east-northeast of Indio. S. S. Goldich, analyst. (May possibly be Late Paleozoic.)

10. Atolia quartz diorite; just south of Atolia, 4½ miles southeast of Randsburg. R. B. Ellestad, analyst.

17. Bell Mountain quartz diorite; 4½ miles east-northeast of Victorville. R. W. Perlich, analyst.

28. Granodiorite; 6 miles a little east of north of Goffs, middle-eastern San Bernardino County. R. B. Ellestad, analyst.

23. Isabella granodiorite; three-fourths mile east of Isabella, 4 miles south of Kernville. G. Kahan, analyst.

3. Lowe granodiorite; One third mile south of Switzerland Camp, 4½ miles northeast of La Canada in southwestern San Gabriel Mountains. R. W. Perlich, analyst.

22. Granodiorite; San Juan Canyon in Santa Ana Mountains, 2 miles east of Orange County line. R. W. Perlich, analyst.

8. Victorville granodiorite; three-fourths mile east of Victorville. R. B. Ellsted, analyst.

18. Coxcomb granodiorite; Eastern part of Colorado River Aqueduct Tunnel in the Coxcomb Mountains. R. W. Perlich, analyst.

7. Descanso granodiorite; near Descanso Junction, San Diego County. L. C. Armstrong, analyst.

14. White Tank quartz monzonite; Colorado River Aqueduct Tunnel in the Eagle Mountains, 7 miles west-northwest of Desert Center. R. B. Ellestad, analyst.

20. Quartz monzonite; by the main road 6½ miles southwest of Baker. R. W. Perlich, analyst.

9. Quartz monzonite; 6½ miles north-northwest of Cadiz, in the Marble Mountains. R. B. Ellestad, analyst.

16. Cactus quartz monzonite; west side of Cactus Flat, in the San Bernardino Mountains. R. W. Perlich, analyst.

Seven analyses of granodiorites of the Late Mesozoic plutonic series are given in Table 2. These are generally more acidic than the quartz diorites, but the two are often gradational. No. 28 from northeast of Goffs (Miller, 1944c, p. 120) is light pinkish gray, massive, and porphyritic, with pink, anhedral to subhedral phenocrysts of microcline, 1 to 4 centimeters in length, irregularly scattered through a coarser medium-grained groundmass. A little protoclastic granulation shows in the thin section. The oligoclase, which is almost albite, is considerably zoned and somewhat altered.

No. 23 represents the Isabella granodiorite of the Kernville quadrangle (Miller, 1931, p. 344–349). This rock is gray, medium-grained, massive, and granitoid. Some of the oligoclase is subhedral and faintly zoned. The microcline is considerably decomposed.

The Lowe granodiorite (Table 2, No. 3) represents the most common facies of that rock in the San Gabriel Mountains (Miller, 1934, p. 41–46). It is light pinkish gray and crudely gneissoid with pink, subhedral, potash feldspar phenocrysts, 1 to 4 centimeters in length, arranged more or less parallel to the foliation. In thin section there is seen to be much protoclastic granulation mostly forming zones between quartz and feldspar grains, but in part cutting into feldspars.

No. 22 is typical of the granodiorite in the southeastern part of the Santa Ana Mountains. The analyzed specimen is light pinkish gray, massive, medium-grained, equigranular, and hypiodiomorphic, with small biotites often euhedral to subhedral. The calcic oligoclase is often subhedral and notably zoned.

The Victorville granodiorite (Table 2, No. 8) from near Victorville (Miller, 1944b, p. 105–106) is very much like No. 22.

The Coxcomb granodiorite (Table 2, No. 18) is typical of that rock from the middle Coxcomb Mountains (Miller, 1944a, p. 64). It is light gray, massive, medium grained, and granitoid. The oligoclase is calcic. There is a little evidence of deuteric activity.

No. 7, Table 2, is typical of the Descanso granodiorite of middle southern San Diego County (Miller, 1935a, p. 127–128). The rock is light pinkish gray, coarser medium-grained, somewhat gneissoid, rather inequigranular and allotriomorphic. There is considerable protoclastic granulation, especially between the larger mineral grains. The oligoclase is almost albite.

In contrast to the quartz diorites, the seven analyzed granodiorites are more acidic, richer in potash feldspar, and the plagioclase is oligoclase which, in some cases, is almost albite. Some biotite is always present, but hornblende is either scarce or absent. The granodiorites often vary to quartz monzonites.

There are four analyses of quartz monzonite facies of the Late Mesozoic plutonic series. One of these (Table 2, No. 14) is typical of the White Tank quartz monzonite (Miller, 1938, p. 438–443) from the Eagle Mountains. This rock is light pinkish gray, massive, moderately coarse-grained, and granitoid. The CO_2 was omitted from calculation of the norm.

No. 20 represents the area of quartz monzonite 6 to 8 miles southwest of Baker. Megascopically it appears ash-gray, massive, coarser medium-grained, and granitoid. It differs from all other analyzed specimens of the Late Mesozoic plutonic series

TABLE 3.—*Chemical analyses, norms, and modes of Tertiary dike rocks*

ANALYSES

	26	29
SiO_2	66.06	72.05
Al_2O_3	15.98	13.57
Fe_2O_3	1.50	1.02
FeO	1.03	.88
MgO	1.00	.62
CaO	3.11	1.49
Na_2O	4.39	3.55
K_2O	3.21	4.50
H_2O^+	1.10	.61
H_2O^-	.05	.08
CO_2	1.74	.91
TiO_2	.56	.32
ZrO_2	.02	.02
P_2O_5	.19	.10
MnO	.04	.04
	99.98	99.76

NORMS	26	29
Q	25.32	33.12
or	18.90	26.69
ab	37.20	29.87
an	3.34	.83
C	4.08	2.55
hy	2.50	1.36
mt	1.62	1.39
il	1.06	.61
ht	.32	
ap	.34	.34
calc	4.00	2.10
	98.68	98.86

MODES (Wt. percentages)	26	29
Quartz	10.0	25.0
Orthoclase	9.0	26.0
Plagioclase	20.0	18.0
Kind of Plag.	Ol.	Ol.
Myrmekite		24.0
Biotite	1.4	
Chlorite	2.0	2.2
Magnetite	2.0	1.0
Sericite	6.0	2.0
Sphene	.5	.5
Epidote		.2
Apatite	.2	.1
Zircon	.1	.1
Calcite	3.0	1.0
Groundmass (Indet.)	46.0	
	100.2	100.1

26. Quartz latite porphyry; from big dike one-third mile south of Desert Center. G. Kahan, analyst.
29. Rhyolite porphyry; from dike 8 miles north-northeast of Goffs. R. B. Ellestad, analyst.

because all the feldspar is microperthite which is ash-gray. In thin section tiny veinlets of granular quartz cut through some of the feldspar and quartz grains, and there are some tiny veins filled with magnetite, suggesting deuteric activity.

The quartz monzonite (Table 2, No. 9) from the Marble Mountains north-northeast of Cadiz is pinkish gray, massive, medium-grained, and granitoid. There is some protoclastic granulation.

No. 16 is an analysis of Cactus quartz monzonite from Cactus Flat in the San Bernardino Mountains. Vaughan calls the rock from this area "Cactus granite" (Vaughan 1922, p. 365), and Woodford and Harriss (1928, p. 271–272) describe "Cactus granite" from an area several miles northeast of Cactus Flat. The analyzed specimen is light pinkish gray, massive, medium-grained, subequigranular, and allotriomorphic. The oligoclase is partly zoned, the biotite is partly chloritized, there is some protoclastic granulation, and some plagioclases are filled with tiny biotites.

Tertiary dikes.—Table 3 shows chemical analyses, norms and modes of two Tertiary dike rocks. No. 26, from the large dike at Desert Center (Miller, 1944a, p. 65), is typical of the quartz latite prophyry dikes so widely distributed in southern California. Megascopically the rock is light greenish gray and porphyritic, with many eudhedral to subhedral oligoclase phenocrysts 3–4 millimeters in length and some elongate chloritized biotites, scattered through a groundmass which is holocrystalline, but so fine-grained as to be largely indeterminate. The oligoclase is sodic. Sericite, chlorite, altered feldspars, and calcite (probably primary) indicate much deuteric action.

No. 29, Table 2, is a rhyolite porphyry from the system of dikes north of Goffs in the Needles map area (Miller, 1944c, p. 123–124). The analyzed rock is megascopically light-gray and holocrystalline with a generally fine-grained groundmass through which are scattered anhedral to euhedral phenocrysts of feldspar 2–15 millimeters in length; some anhedral quartz phenocrysts 2–8 millimeters in length; and a few elongate, subhedral, chloritized biotites. Numerous small myrmekite grains constitute much of the groundmass whose grains have dimensions of less than 1 milimeter. The sodic oligoclase phenocrysts are much decomposed, and their edges are usually corroded. The quartz phenocrysts, which have been rounded by corrosion, are embayed locally with groundmass, and some veinlets of groundmass cut into and through them. Thus there is much evidence of deuteric alteration. The calcite seems to be primary.

CORRELATIONAL PROBLEMS

PRE-CAMBRIAN

Rocks believed to be of pre-Cambrain age are widespread in southern California and were seen by the writer in more than half the 30 described areas. San Diego and southwestern Riverside County comprise the largest region in which these very ancient rocks have not been recognized with some degree of certainty.

Hershey (1902a, p. 273) stated that the older (pre-Cambrian) crystalline rocks of southern California had received little attention, and he described and tentatively correlated some of these rocks which he found in Los Angeles County, western San Bernardino County, and southeastern Kern County. For 20 years after Hershey's work, very little was done on the crystallines. From about 1922 to 1945 a number of workers published papers on areas of crystalline rocks in southern California, but, with the exception of those by the writer, only a few of these papers give more than very brief descriptions of the older crystallines.

The present paper includes the first attempt to bring together data in regard to the pre-Cambrian rocks of southern California and to offer criteria for their correlation in widely separated regions.

Highly metamorphosed sediments, diorite and metadiorite, and granite and metagranite, named in order of age, are the chief older pre-Cambrain rocks of southern California. Some associated amphibolites may represent much altered volcanics. In various areas the metasediments are definitely present, and in some places they are pure enough and in sufficient quantity to warrant separate mapping. In various other areas, however, there is little if any positively recognizable metasedimentary material. By far most of the dioritic rocks (usually basic types) are variably metamorphosed, often highly so, with only cores of the original rock remaining massive. Only scattered, small remnants of these once-widespread dioritic rocks are mappable. In the ever-present granitic rocks, primary foliation and protoclastic granulation are almost invariably developed, usually to a high degree. There is also some evidence of post-consolidation alteration. The granitic rocks are usually more or less contaminated as a result of digestion of country rock, particularly diorite. The granitic rocks are commonly so closely involved with the older rocks that they seldom occur in sufficiently large areas to permit separate mapping. The three main components of the older pre-Cambrian usually form complexes of metasediments and/or dioritic rocks cut to pieces, variably injected *lit-par-lit*, and often more or less digested (particularly the diorite) by the granite and its pegmatitic facies. These complexes nearly everywhere show steep foliation dips. By action of the granite magma upon the older rocks, particularly the diorite, there often developed a syntectic prophyritic gneiss whose medium-grained to moderately coarse-grained, pinkish-gray, crudely foliated, granodioritic groundmass contains many, irregularly scattered, euhedral to subhedral potash feldspars commonly half an inch to 2 inches in length. In the Twenty-nine Palms area, the euhedral feldspars are commonly 2 to 6 inches in length. This porphyritic gneiss occurs in varying amounts in nearly all the widely scattered areas of the complexes regarded as early pre-Cambrian.

The combination of rocks just described exhibits a kind of homogeneity in its heterogeneity, and it clearly indicates profound, wide-spread metamorphism, and granite intrusion accompanied by migmatization, throughout most of southern California. This combination of rocks has characteristics not present in the known Paleozoic and Mesozoic rocks, excepting locally and irregularly in some places near contacts with post-Cambrian intrusives, especially where sediments seem directly to overlie batholithic bodies. Such widespread and persistently profound metamorphism may not prove the older pre-Cambrian age of the rocks so regarded in this paper, but it is, to say the least, strongly indicative. Many years ago Hershey (1902, p. 273) said that workers should "no longer assume that a given outcrop of schist represents strata no older than the Paleozoic for no other reason than a conviction that metamorphism in California is no indicator of age."

We shall now turn to more positive evidence for the great antiquity of the rocks believed to be older pre-Cambrian. Thus the Needles complex underlies, and is separated by a profound unconformity from, definitely known Paleozoic strata, including Cambrian, at several places between Needles and the Marble and Prov-

idence mountains. The highly metamorphosed San Gabriel complex is certainly far older than the Mississippian limestones and quartzites of the northern San Bernardino Mountains, and the northern border of the San Gabriel Mountains.

The Chuckwalla complex is usually not directly associated with known Paleozoic strata, but it underlies the moderately altered Paleozoic formation of the Maria Mountains and the Paleozoic? beds of the Eagle Mountains. Near Randsburg the Johannesburg gneiss is certainly much older than the near-by Paleozoic strata.

The anorthosite of the western San Gabriel Mountains is clearly younger than the San Gabriel complex, and probably older than the Pelona schist. All known, important occurrences of anorthosite in North America, including those of northern New York, southeastern Canada, and southeastern Wyoming, are older pre-Cambrian. All, or nearly all, the known anorthosites of the world are pre-Cambrian, and the writer sees no reason for not assigning the anorthosite of the San Gabriel Mountains to the same age category.

The metasedimentary Rand schist, Pelona schist, and Orocopia schist are regarded as correlatives of pre-Cambrian age, but distinctly younger than the older pre-Cambrian complexes already described. In each area where these schists occur (Table 4) they are faulted against the older complexes, no original contact having been found. The facts that the schists are less highly metamorphosed, and do not contain intimately associated dioritic and granitic rocks which are so characteristic of the adjacent complexes, show that the latter are the older. The Rand schist of the Randsburg area is certainly older than the moderately altered Paleozoic strata of the near-by El Paso Mountains. The Pelona schist on the northeastern side of the San Gabriel Mountains is quite surely older than the near-by Paleozoic strata of that general area. The Orocopia schist is younger than the Chuckwalla complex, but there are no definitely known Paleozoic strata near by, and so the age of the Orocopia is not so certain. Lithologically, however, the Orocopia is almost exactly like the Rand and Pelona schists. It also seems evident that the older complexes, containing so much plutonic igneous material, must have been profoundly eroded before deposition of the original Rand, Pelona, and Orocopia sediments.

A little beyond the area considered in this paper, Noble (1941, p. 949–950) has found later pre-Cambrian sedimentary rocks, called the Pahrump series, which lie in a belt bordering the southern part of the Death Valley trough. He says that "in general the rocks of the Pahrump series are no more highly metamorphosed than the Paleozoic rocks of the region .... In contrast with the earlier pre-Cambrian rocks, which are all regionally metamorphosed, the Pahrump series exhibits only local metamorphism due to intrusive bodies." In regard to the older pre-Cambrian metamorphic rocks of the same region, Noble (1941, p. 948) says that they are chiefly granitic and dioritic gneisses, with little or no associated metasediments, in the mountains just east of the Death Valley trough, but that paraschists, probably Early pre-Cambrian, occur in the western part of the Avawatz Mountains near the south end of Death Valley.

Murphy (1932, p. 337–348) has described the rocks of the Panamint Range, just west of Death Valley. These include the pre-Cambrian? Panamint metamorphic complex which consists largely of gneisses, schists, and granite-injected metased-

iments, and an Early Paleozoic? series of metasediments, largely slates, schists, quartzites, and dolomitic limestones. Noble (1941, p. 948) calls both these series earlier pre-Cambrian.

Nolan (1943, p. 145), in a review of the pre-Cambrian rocks of the Basin and Range province of California, Nevada, and Utah, says that "there appear to be at least three series of pre-Cambrian rocks" and "that large masses of intrusive igneous rocks have been recognized only in the oldest series."

Noble, Murphy, and Nolan all describe Early pre-Cambrian complexes which seem to be much like the complexes so widespread in the region considered in this paper, and also regarded as of Early pre-Cambrian age. They also mention metasediments younger than the complexes, but which may also be Early pre-Cambrian. These metasediments may be more or less equivalents of the Rand, Pelona, and Orocopia schists far to the west and south, but, of course, positive evidence for such correlation is lacking. The still younger pre-Cambrian Pahrump series of metasediments, described by Noble (1941, p. 949) as resting by profound unconformity upon the earlier pre-Cambrian rocks in the southern Death Valley region, is not known to have a counterpart in the extensive southern California region considered in the present paper.

PALEOZOIC AND PROBABLE PALEOZOIC

Paleozoic fossils have been found in 10 of the 30 areas here described. In 9 of them the fossils occur in moderately metamorphosed limestones of Carboniferous age. In two cases the fossils occur in limestone in metasedimentary-igneous complexes. Fragmentary crinoidal remains in the Maria formation may be as old as Silurian. In the Marble Mountains and the Providence Mountains most Paleozoic systems, including Cambrian, are fossiliferous, with Ordovician and Silurian doubtfully present. The various fossiliferous Paleozoic formations are indicated in Table 4. These are of great importance because of the check they furnish in regard to the ages of closely associated igneous rocks in widely scattered parts of southern California, where lithology alone is often not a satisfactory criterion for age determination and correlation.

Formations or parts of complexes which are very probably Carboniferous occur in at least eight areas: Arrastre quartzite and Saragossa quartzite respectively underlying and overlying the Mississippian Furnace limestone of the northern San Bernardino Mountains; crystalline limestones of the eastern San Gabriel Mountains; the Upper Jurupa series of the Jurupa Mountains; the metasediments of the Shadow Mountains which are almost exactly like the near-by Carboniferous Oro Grande formation; the Sidewinder metavolcanics closely associated with the Oro Grande formation, and the Hinkley Valley complex of the Barstow quadrangle; the metasediments of the Riverside Mountains which are quite certainly correlative with the Paleozoic (Silurian?) Maria formation of the Maria Mountains; and some Cambrian? which occurs in the Piute Mountains.

The Kernville series of the Kernville quadrangle; the Bean Canyon series and related metasediments of the Tehachapi-Rosamond area; and the metasedimentary

series of the Grapevine-Gorman area are very likely correlatives. All three series contain metavolcanics. They are either Late Paleozoic (Calaveras) or pre-Cretaceous Mesozoic, probably the former. Metasediments regarded as probably Paleozoic occur in the Ludlow-Newberry area and in southwestern Imperial County.

PALEOZOIC AND/OR MESOZOIC COMPLEXES

Some Paleozoic (Mississippian?) fossils have been found in the sedimentary-igneous complex of the Paradise Spring area. This complex is almost exactly like the Hinkley Valley complex of the near-by Barstow area, and they are quite certainly correlatives. The writer has found what may possibly be crinoidal remains of Paleozoic age in the Palm Canyon complex. The metasediments of these complexes are, in all respects, so much alike that they are rather confidently regarded as partly, if not wholly, Carboniferous with possibly some rocks as old as pre-Cambrian, and some as young as Early Mesozoic, associated with them.

The metasediments of the Diamond Valley complex are very much like those of the near-by "undifferentiated complex" (Daly, 1935, p. 642) of the lower Jurupa series northwest of Riverside. It is quite certain that they are correlatives. A conspicuous development of crystalline limestone like that of the upper Jurupa series, overlying the "undifferentiated complex," has not been found in the Diamond Valley complex. Since this limestone is very probably Late Paleozoic, the complex of the Jurupa series and its probable correlative—the Diamond Valley complex—are at least that old.

The Paleozoic and/or Mesozoic Palm Canyon complex (Miller, 1944a, p. 21–25), called the Paleozoic or older "Metamorphic Series" by Fraser (1931, p. 504–508), on the eastern side of the San Jacinto Mountains, is believed to be partly or wholly correlative with the Diamond Valley complex, but there are certain differences in lithology. Thus white to bluish-gray, crystalline limestone (locally dolomitic) is very abundant in the Palm Canyon complex and interbedded with biotite schists, biotite-quartz schists, and quartzites. The schists and quartzites, much like those of the Diamond Valley complex, are variably *lit-par-lit* injected and replaced, but usually much more so, by granitic, pegmatitic, and silexitic materials which are certainly older than the Late Mesozoic San Jacinto batholith. Metavolcanics occur in the Diamond Valley complex, but none were seen in the Palm Canyon complex. No occurrences of typical, limestone-rich Palm Canyon complex and of typical Diamond Valley complex were seen to come together; they are separated by the San Jacinto fault zone.

The Elsinore series contains volcanics associated with fossiliferous Triassic strata, and there may also be associated Paleozoic strata. The Diamond Valley complex contains some fossiliferous Mississippian beds and metavolcanics which latter may be Triassic. Possibly some pre-Cambrian rocks may also be associated. The Diamond Valley complex and the Elsinore series seem to merge in the Perris Block, and so they seem to be partly, or wholly, of the same age—that is, Late Paleozoic-Triassic.

The Julian schist complex of San Diego County is, in all important respects, much like the Diamond Valley complex of the adjoining Perris Block, and they are rather confidently regarded as largely, or wholly, of the same general age.

General Age	San Gabriel Mountains	Santa Monica Mountains	San Bernardino Mountains	Little San Bernardino Mountains	San Jacinto Mountains	Jurupa
Quaternary			Basalt			
Late Tertiary		Volcanics?				
Middle Tertiary	Volcanics	Volcanics				
	Diabase dikes	Basaltic dikes and sills				
	Q. latite por. dikes Lamprophyre dikes	Trachyte dikes				
Late Mesozoic	Aplite and peg. dikes	Aplite and pegmatite	Pegmatite dikes	Pegmatite dikes	Pegmatite dikes	Plutonic series: Pegmatite
	Lowe granodiorite	Lowe granodiorite?	Cactus granite	White Tank q. monzonite varying to granite and to q. diorite	Q. monzonite varying to granite and to q. diorite	Granite p Q. monzo
	Wilson q. diorite	Wilson q. diorite	Wilson q. diorite?			Ferris q. Q. norite
Mesozoic or Late Paleozoic				Fargo q. diorite	Bradley granodiorite	
Triassic and Probable Triassic		Santa Monica slate				
Paleozoic and/or Mesozoic Complexes					Palm Canyon complex, (Metasediments variably granite-injected)	
Paleozoic and Probable Paleozoic	Metasediments (Paleozoic?)		Saragossa quartzite Furnace limestone (with Carboniferous fossils) Arrastre quartzite			Jurupa series: Sky Blue stone Quartzite Chino crys Undifferen (Metase
Younger Pre-Cambrian	Pelona schist (metasedimentary)		Pelona schist (metasedimentary)			
Older Pre-Cambrian	Dioritic dikes		Lamprophyre dikes			
	Anorthosite					
	Echo granite			Berdoo granite		
	San Gabriel complex		San Gabriel complex	San Gabriel complex		
	Rubio diorite and metadiorite Placerita metasediments			Diorite and metadiorite		

ttle San Bernardino Mountains	San Jacinto Mountains	Jurupa Mountains	Riverside-Elsinore-Coahuila Area	Santa Ana-Elsinore Mountains	Central and
				Volcanics and sills	
gmatite dikes ite Tank q. monzonite varying to granite and o q. diorite	Pegmatite dikes Q. monzonite varying to granite and to q. diorite	PLUTONIC SERIES Pegmatite dikes Granite porphyry Q. monzonite porphyry Perris q. diorite Q. norite	PLUTONIC SERIES Pegmatite and aplite Granitic rocks La Posta q. diorite Cajalco q. monzonite Lakeview q. monzonite Perris and Estelle q. diorite (Val Verde tonalite) Virginia q. norite Gavilan Peak gabbro	Q. monzonite Q. diorite	PLUTONIC SERIES Pegmatite Rattlesnal La Posta Woodson gran Lakeview Bonsal to Green Val Cuyamaca cos gab
rgo q. diorite	Bradley granodiorite				Granodiorite? Mesozoic?)
			ELSINORE SERIES Temescaldacite porphyry Metavolcanics Metasediments	ELSINORE SERIES Metavolcanics Metasediments (with Triassic fossils)	Black Mountai
	Palm Canyon complex, (Metasediments variably granite-injected)		Diamond Valley complex (Metasediments and metavolcanics variably granite-injected; with Carboniferous fossils)		Julian schist (sediments v injected)
		JURUPA SERIES Sky Blue crystalline limestone Quartzite and schist Chino crystalline limestone Undifferentiated complex. (Metasedimentary)			
rdoo granite n Gabriel complex orite and metadiorite			Box Springs complex (may be much younger)		

San Diego County		Imperial County		Palm Springs-Blythe Area	Twenty-N
al and northwestern	Southern	Southwestern	Northern and eastern		
			Volcanics (obsidian and pumice)		
	Jacumba volcanics	Jacumba volcanics	Volcanics (basaltic)	Volcanics (basaltic)	
		Volcanics (in Coyote Mtn.)			
	Basaltic dikes		Volcanics (andesitic)	Basic dikes	
			Q. latite porphyry dikes	Q. latite porphyry dikes	Q. latite Basic dike
matite dikes	Pegmatite dikes				
tlesnake granite	Granitic rocks	Granitic rocks			
Posta q. diorite	La Posta q. diorite	La Posta q. diorite	Q. monzonite	Pegmatic dikes Coxcomb granodiorite	Aplite and
dson and Stonewall granodiorite	Descanso granodiorite			White Tank q. monzonite	White Tan
eview tonalite				San Jacinto granodiorite	
sal tonalite	Harbison q. diorite		Q. diorite		
en Valley tonalite	Alpine q. diorite				
amaca and San Mar-os gabbro	Viejas gabbro-diorite				
iorite? (Early zoic?)	Granodiorite? (Early Mesozoic?)			(Fargo Canyon q. diorite Bradley granodiorite)	
Mountain volcanics	Black Mountain volcanics				
chist (complex) (Meta-ents variably granite-ed)	Julian schist (complex) (Metasediments variably granite-injected)			McCoy Mountains formation (Metasedimentary-metavolcanic complex) Palm Canyon complex (Metasediments variably granite-injected) Maria-plutonic complex	
		Metasediments (with Paleozoic fossils?)		Metasediments (with iron ore)	
				Maria formation (Metasediments with fossils)	
				Orocopia schist (metasedimentary)	
			Granite (contaminated)		
			Tumco formation		Palms gra
			Vitrefax formation		Monzoniti (syntect
			Chuckwalla complex	Chuckwalla complex	Pinto gnei Gold Park Meta sedi

TABLE 4.—*Correlation of crystalline rocks of southern California*

County	Palm Springs-Blythe Area	Twenty-Nine Palms Area	Riverside-Whipple Mountains	Needles-Goffs Area	Old Wom
Northern and eastern					
lcanics (obsidian and pumice)					
lcanics (basaltic)	Volcanics (basaltic)			Volcanics (basaltic)	
			Volcanics (andesitic)	Volcanics (andesitic)	Volcanics (
lcanics (andesitic)				Rhyolite porphyry dikes	
	Basic dikes			Basic dikes	
latite porphyry dikes	Q. latite porphyry dikes	Q. latite porphyry dikes Basic dikes		Q. latite porphyry dikes	
				Aplite dikes Granodiorite (possibly Early Tertiary)	
	Pegmatic dikes				
monzonite	PROBABLY SAME AGE Coxcomb granodiorite	Aplite and pegmatite			Q. monzoni
	White Tank q. monzonite	White Tank Q. monzonite			
diorite	San Jacinto granodiorite				
	(Fargo Canyon q. diorite Bradley granodiorite)				
	McCoy Mountains formation (Metasedimentary-metavolcanic complex) Palm Canyon complex (Metasediments variably granite-injected) Maria-plutonic complex				
	Metasediments (with iron ore)			Metasediments (with carboniferous fossils)	
	Maria formation (Metasediments with fossils)		Maria? formation (Metasedimentary)		Quartzite
	Orocopia schist (metasedimentary)				
Granite (contaminated)					
Tumco formation		Palms granite		NEEDLES COMPLEX Granite	Kilbe
Vitrefax formation		Monzonitic porphyry (syntectic)		Fenner gneiss (syntectic porphyry)	Fenn po
uckwalla complex	Chuckwalla complex		Chuckwalla complex	Diorite and metadiorite	Diori
		Pinto gneiss (complex) Gold Park gabbro Meta sediments		Metasediments	Esse

D WOMAN-PIUTE MOUNTAINS	AMBOY-CADIZ AREA	PROVIDENCE MOUNTAINS	BAKER AREA	LUDLOW-NEWBERRY AREA	
				Basaltic flows and tuffs	
				Rhyolitic flows and tuffs	
	Volcanics		Volcanics	Black Mountain basalt	
				Red Mountain andesite	
				Rosamond series (Non-marine seds. and volcs.)	
anics (andesitic)	Volcanics and intrusive plugs (andesitic and rhyolitic)	Volcanics	Volcanics		
		Rhyolite porphyrydikes			
			Basic dikes	Basic dikes	
			Q. latite porphyry dikes	Acidic dikes Q. porphyry	
nonzonite	Q. monzonite	Q. monzonite (possibly Early Tertiary)	Q. monzonite (Late Mesozoic?)	Pegmatite and aplite	
				Cactus granite	
				Pink granite Q. monzonite	
		Strata (with fossils)		ORE MT. GROUP: Intrusive metaporphyry	
				ORE MT. GROUP: Volcanics (andesitic)	
	STRATA WITH FOSSILS: Carboniferous	STRATA WITH FOSSILS: Permian			
		Pennsylvanian			
		Mississippian	Limestone (with carboniferous fossils)	Metasediments (Paleozoic?)	
	Devonian?	Devonian			
rtsite (Cambrian?)	Ordovician-Silurian?	Ordovician-Silurian			
	Cambrian	Cambrian			
Kilbeck granite (gneiss)	NEEDLES COMPLEX: Granite rocks		HALLORAN COMPLEX: Granitic rocks	COMPLEX: Granitic rocks	
Fenner gneiss (syntectic porphyry)	Monzonitic porphyry (syntectic)		Monzonitic porphyry (syntectic)	Monzonitic porphyry (syntectic)	
Diorite and metadiorite	Diorite and metadiorite	Needles complex	Diorite and metadiorite	Diorite and metadiorite	
Essex series (metasediments)	Metasediments		Metasediments	Metasediments	

Baker Area	Ludlow-Newberry Area	Barstow Quadrangle	Paradise Spring Area	Shadow Mountains-Wilsona Area	Randsburg Area
	Basaltic flows and tuffs				
	Rhyolitic flows and tuffs				
Volcanics	Black Mountain basalt		Black Mountain basalt		Black Mountain basalt
	Red Mountain andesite	Volcanics	Red Mountain andesite		Red Mountain andesite
	Rosamond series (Non-marine seds. and volcs.)		Rosamond series ((Non-marine seds. and volcs.)		Rosamond series (non-marine seds. and tuffs)
Volcanics					
Basic dikes	Basic dikes	Basic dikes			Basic dikes
Q. latite porphyry dikes	Acidic dikes Q. porphyry	Q. latite porphyry dikes			Q. latite porphyry dikes
Q. monzonite (Late Mesozoic?)	Pegmatite and aplite	Pegmatite and aplite			Pegmatite and aplite
	Cactus granite	Victorville q. monzonite	Q. monzonite	Q. monzonite	Atolia q. monzonite varying to q. diorite
	Pink granite Q. monzonite				Q. diorite
		(Bell Mountain diorite Iron Mountain gabbro)	Q. diorite	Q. diorite	
	ORD. MT. GROUP: Intrusive metaporphyry	Intrusive metaporphyry			
	ORD. MT. GROUP: Volcanics (andesitic)				
		Hodge complex (mainly dioritic and granitic)	Hodge complex?	Hodge complex (dioritic and granitic rocks)	
		Hinkley Valley complex (mainly metasediments)	Hinkley Valley complex (mainly metasediments; with carboniferous fossils)		
Limestone (with carboniferous fossils)	Metasediments (Paleozoic?)	Sidewinder Valley Meta-volcanics Oro Grande metasediments (with carboniferous fossils)		Oro Grande metasediments	
					Rand schist (metasedimentary)
HALORAN COMPLEX: Granitic rocks	COMPLEX: Granitic rocks				
HALORAN COMPLEX: Monzonitic porphyry (syntectic)	COMPLEX: Monzonitic porphyry (syntectic)				Johannesburg gneiss (metasedimentary-plutonic complex)
HALORAN COMPLEX: Diorite and metadiorite	COMPLEX: Diorite and metadiorite				
HALORAN COMPLEX: Metasediments	COMPLEX: Metasediments				

	El Paso Mountains	Kernville Quadrangle	Tehachapi-Rosamond Area	Grapevine-Gorman Area	Lake Hughes-Acton Area
lt	Black Mountain basalt	Basalt and andesite			
ite	Ricardo beds (with volcanics)				
n-	Rosamond? series		Rosamond series (non-marine seds. and volcs.)		
ffs)					
					Escondido series (non-marine seds. and volcs.)
	Basaltic dikes				Basaltic dikes
kes					
					Lamprophyre dikes
		Pegmatite and aplite			Pegmatite and aplite
	Atolia q.-monzonite	Isabella granodiorite varying to q. monzonite and to q. diorite	Q. monzonite	Q. monzonite	Lowe granodiorite
te					Q. syenite
	Q. diorite			Q. diorite	Parker q. diorite
					Wilson diorite
		Sacatur q. diorite	Q. diorite		
		Summit gabbro-diorite			
	Later Paleozoic strata (with fossils)	Kernville series (metasediments with some metavolcanics; carboniferous?)	Metasediments with some metavolcanics; including Bean Canyon series (probably same as Kernville series)	Metasediments with some metavolcanics (probably same as Kernville series)	
	Early Paleozoic? quartzite				
					Pelona schist (metasedimentary)
					Dioritic facies of anorthosite
				San Gabriel complex	San Gabriel complex

In the Maria Mountains, the metasediments of the Maria-plutonic complex are quite certainly correlative with the adjacent Maria formation which contains Paleozoic (Silurian?) crinoidal remains.

Some areas of the Hodge complex in the Barstow area contain considerable metasedimentary material which is correlative with the Hinkley Valley metasediments.

In all the Paleozoic and/or Mesozoic complexes just mentioned—Palm Canyon, Julian schist, Diamond Valley, Jurupa, Paradise Spring, Hinkley Valley, Maria-plutonic, and Hodge—the metasediments are cut more or less intimately by plutonic rocks. In most cases dioritic rocks were first emplaced, usually in moderate amounts. In all cases granitic, pegmatitic, and silexitic materials, varying in amount and in place, cut both metasediments and metadiorite, usually parallel to the foliation or bedding, often in *lit-par-lit* fashion resulting in banded gneisses, and in granitization and local replacement of nonlimy beds of the metasediments. Such migmatites often bear considerable resemblance to the Early pre-Cambrian complexes, but the process of migmatization was usually more local and less thorough, and the associated metasediments generally represent lower-grade metamorphism. Apparently such migmatization of the Paleozoic metasediments occurred only where conditions were unusually favorable, that is near roofs or borders of granite or quartz monzonite batholiths from which large amounts of highly mobile and penetrative pegmatitic and silexitic meterial emanated into adjacent bedded or foliated country rocks. Such attack on older rocks by granitic material was not on a wholesale, regional scale as as was the case in Early pre-Cambrian time, and it was generally much less effective.

What is the age of the dioritic and granitic intrusives which first cut and more or less intimately injected the metasediments to produce the various complexes here under consideration? Evidence has been presented in considerable detail (Miller, 1944a, p. 22–25) showing that metasediments of the Palm Canyon complex were first cut by some sills of diorite and then variably cut, granitized, *lit-par-lit* injected, and in part replaced by granitic, pegmatitic, and silexitic material before intrusion of the Bradley granodiorite and the still later, massive, Late Mesozoic San Jacinto granodiorite. Now, if the metasediments of the Palm Canyon complex are rather Late Paleozoic, as they probably are, the earlier dioritic and granitic intrusives may be as old as Late Paleozoic or as young as Late Mesozoic.

As already indicated, the metasediments of the Diamond Valley complex, with Paleozoic fossils, and its almost certain general correlative—the Julian schist complex—were also metamorphosed and more or less intimately injected with granitic and pegmatitic material before they were cut by certain younger members of the Late Mesozoic plutonic series such as the La Posta quartz diorite. This granitic material, for reasons already given, in part probably came from Late Mesozoic granodiorite, and in part from a still older (Late Paleozoic?) source. A similar relationship seems to be true of the "undifferentiated complex" of the Jurupa series.

Metasediments of the Hinkley Valley, Hodge, and Paradise Spring complexes were cut first by sills of diorite and metadiorite after which the combination was cut more or less intimately and injected by granitic, pegmatitic, and silexitic material much as in the case of the Palm Canyon complex; the limestone beds were least affected. The granite, which is most abundant in the Hodge complex, is usually considerably foliated

and altered, and it seems to be older than the generally massive Victorville quartz monzonite somewhat farther south. Both the diorite and the granite may be Late Paleozoic or Early Mesozoic, but there is no proof that one or both may not be Late Mesozoic. The finding of Paleozoic fossils in the Paradise Spring complex almost completely rules out the possibility that its components, as well as that of the Hodge and Hinkley Valley complexes, might be of pre-Cambrian age as formerly suggested (Miller, 1944b, p. 97–98).

The Paleozoic metasediments of the Maria-plutonic complex were cut first by sills of diorite and metadiorite, and then more or less intimately by much granitic and pegmatitic material. The writer has given reasons for tentatively assigning these intrusives to the Late Paleozoic (Miller, 1944a, p. 31). The Maria-plutonic complex is, in many ways, much like the Palm Canyon complex.

Descriptions of the Arrastre quartzite, Furnace limestone (Paleozoic), and Saragosa quartzite by Vaughan (1922, p. 352-361) are, in some respects, like the writer's description of the Palm Canyon complex (Miller, 1944a, p. 21–25), even with suggestions that they (especially the Arrastre) were intimately injected with granitic material before entry of the Late Mesozoic granite. Could such earlier granite be Late Paleozoic or Early Mesozoic?

Mention of the McCoy Mountains formation should here be made because it is a metavolcanic-metasedimentary complex which Hazard, Gardner, and Mason (1938, p. 279) assign to the Early Mesozoic, but which the writer believes is more likely Late Paleozoic (Miller, 1944a, p. 52). This complex is probably correlative with the interbedded Oro Grande metasediments and Sidewinder Valley metavolcanics of the Victorville area.

TRIASSIC AND PROBABLE TRIASSIC

Triassic marine strata with fossils occur in the Providence Mountains and in the Santa Ana Mountains (Elsinore series) as already pointed out. The Santa Monica slate of the Santa Monica Mountains is rather confidently correlated with the Elsinore series for reasons already given.

The metavolcanics of the Elsinore series are Triassic, and the Temescal dacite porphyry of the Perris Block is very probably Triassic.

The Black Mountain volcanics of western San Diego County are either Late Triassic or Jurassic according to Hanna (1926, p. 204). They are definitely older than the Late Mesozoic plutonic series of that region.

The Ord Mountain volcanics of the Newberry Mountains-Ludlow area are Triassic or Early Jurassic, probably the former, according to Gardner (1940, p. 270). They are quite certainly distinctly younger than the Late Paleozoic Sidewinder Valley metavolcanics of the near-by Victorville area.

MESOZOIC OR LATE PALEOZOIC INTRUSIVES

In this category are diorites in various areas. Thus the closely related Summit and Sacatar diorites of the southern Sierra Nevada (Miller and Webb, 1940, p. 353–356) cut the Kernville series (Late Paleozoic or possibly Late Mesozoic), and they are in

turn cut by the Late Mesozoic Isabella granodiorite. The two diorites may, therefore, be as old as Late Paleozoic or as young as Late Mesozoic, probably the latter, but Knopf (1929, p. 19) suggests that some diorite of the Mother Lode district is Late Paleozoic.

The Bradley granodiorite of the Palm Springs-Indio area (Miller, 1944a, p. 58–59) is distinctly older than the San Jacinto granodiorite batholith and younger than the Late Paleozoic? Palm Canyon complex. Thus, it may be as old as Late Paleozoic or as young as Late Mesozoic, probably the latter. Reasons have been given (Miller, 1944a, p. 60) for correlating the Fargo Canyon diorite of the Little San Bernardino Mountains with the Bradley granodiorite, and both are probably approximate correlatives of the Wilson and Perris quartz diorites.

The Bell Mountain diorite of the Victorville area cuts Carboniferous strata and is, in turn, cut by the Late Mesozoic Victorville quartz monzonite. The Iron Mountain gabbro-diorite of the near-by Barstow area is probably correlative with it. These diorites, then, may be as old as Late Paleozoic or as young as Late Mesozoic, probably the latter (Miller, 1944b, p. 104–105).

As already pointed out, the diorite of the Hinkley Valley and Hodge complexes. in the Barstow and Paradise Spring areas, is either Late Paleozoic or Late Mesozoic. The same is probably true of the quartz diorite of the Shadow Mountains-Wilsona area.

LATE MESOZOIC INTRUSIVES

These rocks are very widespread and extensively exposed in southern California in the form of batholiths, stocks, and dikes. They range from gabbro to granite, with quartz diorite, granodiorite, and quartz monzonite most abundantly represented. Such rocks comprise a plutonic series which constitutes that part of the great Peninsular Mountains batholith extending from the general vicinity of Riverside into Lower California. In this batholith the more basic magma was usually emplaced, and more or less consolidated, before entry of the more acidic magma. The Wilson quartz diorite in the San Gabriel Mountains bears a similar relationship to the Lowe granodiorite as does the quartz diorite to the Atolia quartz monzonite in the Randsburg and El Paso Mountains areas; and quartz diorite to quartz monzonite in the Grapevine-Gorman, Tehachapi-Rosamond, and Lake Hughes-Acton areas, and probably also in the San Bernardino Mountains, Santa Monica Mountains, and eastern Imperial County. The extensive Late Mesozoic batholith of the southern Sierra Nevada (*e.g.*, Kernville quadrangle) varies from quartz diorite through granodiorite and quartz monzonite to granite, with granodiorite perhaps most abundant. The associated Sacatar quartz diorite probably represents an early magmatic facies of the batholith, but as already pointed out it may be still older (Late Paleozoic?).

It is significant that little, if any, diorite is closely associated with the Late Mesozoic batholithic rocks of the eastern half of the 40,000-square mile area of southern California considered in this paper. These batholithic rocks are quartz monzonite and granodiorite, varying to granite, as excellently shown in the following areas:

Twenty-nine Palms; Desert Center (Eagle and Coxcomb Mountains); Ludlow-Newberry Mountains; Amboy-Cadiz; Old Woman-Piute Mountains; Providence Mountains; Baker; and Needles-Goffs.

There is good evidence that the Late Mesozoic batholithic rocks of southern California and adjacent regions show considerable range in age from Late Jurassic to Middle Cretaceous, and possibly even to Early Tertiary. More or less satisfactory evidence supporting this conclusion will now be presented.

Hinds (1934, p. 192) concluded "that the folding and igneous [batholithic] invasion in the Sierra Nevada postdates the Mariposa [late, but not latest, Jurassic] deposition, and antedates the submergence beneath Chico (Late Cretaceous) seas. Reasoning from the relations previously described (p. 190–191) from the Klamath Mountains, both events took place before the opening of Cretaceous time. Taliaferro (1942, p. 105) concluded that the Nevadan Revolution began in Late Jurassic time (post-Mariposa and pre-Franciscan) and reached a climax at, or somewhat before, the close of the period, and that the batholithic intrusions which in part accompanied, and in part followed, the orogeny may have continued into Early Cretaceous time. The present writer believes that such intrusions could not have extended very far into the Cretaceous because oldest Upper Cretaceous (Chico) strata rest unconformably upon the batholithic rocks. This means that much, if not all, of Early Cretaceous time was needed to lay bare the intrusives.

Relatively small plutons, varying from quartz diorite to granodiorite, in the middle Coast Range of California are pre-Cretaceous and almost certainly older than the Upper Jurassic Franciscan formation (Trask, 1926, p. 136). These are probably of about the same age as the older part of the Sierra Nevada batholith.

In the Santa Ana and Elsinore mountains, the batholithic masses cut Triassic rocks and are overlain unconformably by early Upper Cretaceous beds which means that they cannot be younger than very Early Cretaceous or older than Jurassic.

In San Diego County the batholithic masses cut the Julian schist (Triassic and/or Late Paleozoic). In the western part of the county the Alpine quartz diorite member of the batholith cuts the Black Mountain volcanics which are regarded as Late Triassic or Jurassic by Hanna (1926, p. 203–204), and the diorite is probably older than near-by Upper Cretaceous (Chico) strata (Hanna, 1926, p. 222), but it may be as young as Middle Cretaceous.

Böse and Wittich (1913, p. 347–351) report that in northern Lower California intrusives, including diorite and granite, cut Middle Cretaceous strata and are overlain unconformably by Late Cretaceous strata. Several other workers have confirmed this conclusion. Thus Woodford and Harriss (1938, p. 1331) say that "The Sierra Nevada composite batholith seems to be somewhat older than the corresponding Peninsular (range) plutons."

Numerous plutons, regarded as Late Mesozoic in this paper, are widely scattered throughout the desert region of southern California. Their age determination is rendered uncertain because of the absence of Jurassic and Cretaceous strata from this region, but they are surely post-Paleozoic and older than Middle Tertiary, and probably wholly or largely Late Jurassic or Cretaceous. A number of small and large

areas in northeastern San Bernardino County, are indicated as "Tertiary granitic rocks" on the state map of 1938. Several of these areas have been examined by the writer, and, as already explained, there seems to be no good reason for calling them Tertiary. Most or all of the granitic rocks of the area northeast of Baker are probably pre-Cambrian. Hewett (1939, p. 1951) says that a quartz monzonite sill accompanied Laramide orogeny in the Ivanpah region, and that (Hewett, 1931, p. 55), in the adjacent region around Goodsprings, Nevada, certain evidence indicates that some granite porphyry dikes and sills are probably Late Jurassic, but that other evidence suggests that they are Late Cretaceous or Early Tertiary. His map shows them as Tertiary. Judging from his meager description, Hewett's granite porphyry dikes and sills are much like rhyolite porphyry dikes which cut the granodiorite pluton 6 to 8 miles north of Goffs (Miller, 1944c, p. 123–124) and regarded by the writer as Early or Middle Tertiary, while this granodiorite, shown on the state map as Tertiary, is regarded by the writer as Late Mesozoic or possibly Early Tertiary.

In the Tucson Mountains of Arizona, Brown (1939, p. 720–721) has found quartz monzonite and granite intrusive into Cretaceous strata. King (1939, p. 1693–1698) has found fairly large masses of granitic and dioritic rocks intrusive into Cretaceous strata and Early Tertiary volcanics in the northern Sierra Madre Occidental of northwestern Mexico.

The evidence above presented indicates strongly that the great, widespread, Late Mesozoic plutonic invasion began before the close of the Jurassic in the Sierra Nevada region and spread generally southeastward into Lower California by the Middle Cretaceous; into the northeastern Mohave Desert possibly as late as the Late Cretaceous or very Early Tertiary; and into southern Arizona and northwestern Mexico in the Early Tertiary. It also seems clear that the greatest volume of the intrusions occurred from the Sierra Nevada well into Lower California and generally diminished in volume eastward into Nevada, Arizona, and northwestern Mexico.

The nature of the rock is not always a sufficient criterion for distinguishing some facies of the Late Mesozoic intrusives from certain facies of the Early pre-Cambrian intrusives (Miller, 1933, p. 161–162). Thus, in some places, granitic and dioritic facies of both these great groups of rocks are remarkably similar in composition and general appearance. In such cases field relations must be depended upon to make the distinction, but, even so, one cannot always be sure in which category the rock is. The Late Mesozoic intrusives, however, very commonly show sharp contacts in contrast with the usual blurred contacts of the Early pre-Cambrian intrusives, and the very common occurrence of intimate mixtures of the latter are exceptional with the former. But where Late Mesozoic granitic magma was locally pegmatitic or silexitic, and therefore exceptionally mobile, and the country rock was well foliated or bedded, such country rock, relatively near contacts, was in places more or less intimately cut and injected, even *lit-par-lit*. Such injection, producing banded gneisses and syntectic rocks, was very widespread in Early pre-Cambrian time. Also the Late Mesozoic intrusives are far more commonly massive, uncontaminated with country rock, and free from protoclastic granulation than the Early pre-Cambrian intrusives.

CENOZOIC IGNEOUS ROCKS

Cenozoic igneous rocks in southern California include both dikes and volcanics. The dike rocks fall into three general categories—quartz latite porphyry, basic (basaltic and diabasic), and rhyolite porphyry. Only in the Needles-Goffs area have all three been found. The age relations are there clear; quartz latite porphyry dikes are cut sharply by the basic dikes, which in turn are cut by the rhyolite porphyry dikes. All three are quite certainly of Early or Middle Tertiary age (Miller, 1944c, p. 121–124).

The quartz latite porphyry and basic dikes are widespread in southern California, as indicated in the correlation chart (Table 4). For reasons given in publications above cited, they are regarded as Early or Middle Tertiary, probably the latter. They tend to occur in groups, often widely separated; this is especially true of the quartz latite porphyry dikes which usually form roughly parallel systems.

Volcanic rocks of Cenozoic age are very widespread in southern California as shown in the chart (Table 4). They include both lavas and pyroclastics, ranging from basalt to rhyolite with andesitic types perhaps most abundant. Early Tertiary volcanics are not definitely known, but those of Middle Tertiary age are abundant and widespread. Late Tertiary and Quaternary volcanics are also important; the latter are found very largely in the middle and eastern Mohave Desert region. Reasons for the various age classifications have already been given.

SUMMARY

Crystalline rocks are widely exposed throughout an area of 40,000 square miles of southern California. Thirty large areas, representing all important crystalline rock types in this large region, are described. Special attention is given to the kinds, distribution, origin, emplacement, ages, relationships, and correlation of the crystallines.

The oldest rocks, rather confidently believed to be Early pre-Cambrian, are, in order of age, metasediments (schists, quartzites, and crystalline limestones), diorite and metadiorite, granite, mixed rocks (including migmatites and syntectics), and anorthosite. Except for the anorthosite, these rocks are all widely distributed. Younger pre-Cambrian rocks, which are mainly metasediments, particularly mica schists, occur in several areas.

Strata of Paleozoic and probable Paleozoic age, usually more or less metamorphosed, are found in various widely distributed areas. Marine fossils found in 10 of the areas range in age from Cambrian to Permian but with Ordovician and Silurian probably missing. There are various small and large areas of Paleozoic and/or Mesozoic complexes, consisting of metasediments cut, and variably injected, by granitic material.

Triassic and probable Triassic strata, usually moderately metamorphosed, occur in several areas, two of which have yielded marine fossils. In at least one area the Triassic sediments are interbedded with metavolcanics.

In a few areas massive to foliated diorites, cut to pieces by quartz monzonites, are either Late Paleozoic or pre-Cretaceous Mesozoic.

The most extensive and widespread plutonic rocks are batholiths, stocks, and dikes of Late Mesozoic age which range from gabbro to granite with quartz diorite, granodiorite, and quartz monzonite most common. The large batholith in the Peninsular Mountains shows a complete range from olivine gabbro through gabbro-diorite, quartz diorite, granodiorite, and quartz monzonite, to granite. Pegmatite, aplite, and silexite dikes usually accompany the intrusives. These Late Mesozoic intrusives are partly or wholly Late Jurassic in the Sierra Nevada, Middle Creataceous in northern Lower California, and possibly as young as very Early Tertiary in northeastern San Bernardino County, thus indicating a progressive wave of intrusion from the Sierra Nevada southeastward.

Quartz latite porphyry dikes and basaltic dikes of Early or Middle Tertiary age are widespread, and there are some rhyolite porphyry dikes of about the same age. Middle and Late Tertiary volcanics are widespread in numerous large and small areas. Considerable areas of Quaternary volcanics are found mainly in the middle and eastern Mohave Desert region.

Chemical analyses of 29 carefully chosen igneous rocks are presented, together with their calculated norms and modes, and with comments on the significance of the analyses.

A table, representing a more or less preliminary correlation of the principal crystalline rocks of southern California, accompanies the paper, and correlational problems are discussed at length.

REFERENCES CITED

Baker, C. L. (1911) *Notes on the later Cenozoic history of the Mohave Desert region in southeastern California*, Univ. Calif. Publ., Dept. Geol. Sci., vol. 6, p. 333–383.

———(1912) *Physiography and structure of the western El Paso Range and the southern Sierra Nevada*, Univ. Calif. Publ., Dept. Geol. Sci., vol. 7, p. 117–142.

Brown, W. H. (1939) *Tucson Mountains, an Arizona basin range type*, Geol. Soc. Am., Bull., vol. 50, p. 697–760.

Buwalda, J. P., Gazin, C. L., and Sutherland, J. C. (1930) *Frazier Mountain, a crystalline overthrust slab, west of Tejon Pass, southern California* (abstract), Geol. Soc. Am., Bull., vol. 41, p. 146–147.

Böse, E., and Wittich, E. (1913) *Informe relativo a la exploracion de la region norte de la costa occidental de la Baja California*, Parergones del Inst. Geol. de Mexico, vol. 4, p. 307–529.

Clark, C. W. (1921) *Lower and Middle Cambrian formations of the Mohave Desert*, Univ. Calif. Publ., Dept. Geol. Sci., vol. 13, p. 1–7

Daly, J. W. (1935) *Paragenesis of the mineral assemblage at Crestmore, Riverside County, California*, Am. Mineral., vol. 20, p. 638–659.

Darton, N. H. (1907) *Discovery of Cambrian rocks in southeastern California*, Jour. Geol., vol. 15, p. 470–473.

——— (1915) In guidebook of the western United States, Part C the Santa Fe route, pp. 145–164 and Sheets 21, 22, 23, 24.

Donnelly, M. (1934) *Geology and mineral deposits of the Julian district, San Diego County, California*, Calif. Jour. Mines Geol., State Mineral., Rept. 30, p. 331–370.

Dudley, P. H. (1935) *Geology of a portion of the Perris Block, southern California*, Calif. Jour. Mines Geol., State Mineral., Rept. 31, p. 487–506.

Eakle, A. S. (1917) *Minerals associated with the crystalline limestone at Crestmore, Riverside County, California*, Univ. Calif. Publ., Dept. Geol. Sci., vol. 10, p. 327–360.

Eckis, R. (1931) *Geologic maps of parts of the Ramona, Oceanside, Escondido, and Indio quadrangle*, Pomona Coll. (unpublished).

Ellis, A. J., and Lee, C. H. (1919) *Geology and ground waters of the western part of San Diego County, California*, U. S. Geol. Survey, W.-S. Paper 446.

English, W. A. (1926) *Geology and oil resources of the Puente Hills region, Southern California*, U. S. Geol. Survey, Bull. 768.

Erwin, H. D., and Gardner, D. L. (1940) *Notes on the geology of a portion of the Calico Mountains, San Bernardino County, California*, Calif. Jour. Mines Geol., State Mineral., Rept. 36, p. 293–304.

Fairbanks, H. W. (1893) *Geology of San Diego; also of portions of Orange and San Bernardino Counties*, Calif. State Min. Bur., Rept. 11, p. 76–120.

Fraser, D. M. (1931) *Geology of San Jacinto quadrangle south of Gorgonio Pass, California*, Calif. State Mineral., Rept. 28, p. 490–540.

Gardner, D. L. (1940) *Geology of the Newberry and Ord Mountains, San Bernardino County, California*, Calif. Jour. Mines Geol., State Mineral., Rept. 36, p. 257–292.

Goodyear, W. A. (1888a) *San Diego County, California*, Calif. State Min. Bur., Rept. 8, p. 516–528.

——— (1888b) *Kern County, California*, Calif. State Min. Bur., Rept. 8, p. 309–324.

Hanna, M. A. (1926) *Geology of the La Jolla quadrangle, California*, Univ. Calif. Publ., Dept. Geol. Sci., vol. 16, p. 187–246.

Harder, E. C. (1912) *Iron-ore deposits of the Eagle Mountains, California*, U. S. Geol. Survey, Bull. 503.

Hazzard, J. C. (1937) *Lower Triassic rocks in San Bernardino County, California* (abstract), Geol. Soc. Am., Pr. for 1936, p. 329.

———, and Crickmay, C. H. (1933) *Notes on the Cambrian rocks of the eastern Mohave Desert, California*, Univ. Calif. Publ., Dept. Geol. Sci. vol. 23, p. 57–80.

———, and Dosch, E. F. (1937) *Archean rocks in the Piute and Old Woman mountains, San Bernardino County, California*, (abstract), Geol. Soc. Am., Pr. for 1936, p. 308–309.

———, and Mason, J. F. (1936) *Middle Cambrian formations of the Providence and Marble mountains, California*, Geol. Soc. Am. Bull., vol. 47, p. 229–240.

———, Gardner, D. L., and Mason, J. F. (1938) *Mesozoic? metavolcanics and sedimentary rocks in San Bernardino and Riverside counties, California* (abstract), Geol. Soc. Am., Pr. for 1937, p. 278–279.

Henshaw, P. C. (1942) *Geology and mineral deposits of the Cargo Muchacho Mountains, Imperial County, California*, Calif. Jour. Mines Geol., State Mineral., Rept. 38, p. 147–196.

Hershey, O. H. (1902a) *Some crystalline rocks of southern California*, Am. Geol. vol. 29, p. 273–290.

——— (1902b) *Some Tertiary formations of southern California*, Am. Geol., vol. 29, p. 349–372.

Hess, F. L. (1909) *Gold mining in the Randsburg quadrangle, California*, U. S. Geol. Survey, Bull. 430, p. 23–47.

Hewett, D. F. (1931) *Geology and ore deposits of the Goodsprings quadrangle, Nevada*, U. S. Geol. Survey, Prof. Paper 162.

——— (1939) *Tertiary history of Ivanpah region, southeastern California* (abstract), Geol. Soc. Am., Bull., vol. 50, p. 1951.

Hinds, N. E. A. (1934) *Jurassic age of last granitoid intrusives in the Klamath Mountains and Sierra Nevada, California*, Am. Jour. Sci., 5th ser., vol. 27, p. 182–192.

Hoots, H. W. (1931) *Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, California*, U. S. Geol. Survey, Prof. Paper 165.

Hudson, F. S. (1922) *Geology of the Cuyamaca region of California, with special reference to the origin of the nickeliferous pyrrhotite*, Univ. Calif. Publ., Dept. Geol. Sci., vol. 13, p. 175–252.

Hulin, C. D. (1925) *Geology and ore deposits of the Randsburg quadrangle, California*, Calif. State Min. Bur., Bull. 95.

Hurlbut, C. S. (1935) *Dark inclusions in a tonalite of southern California*, Am. Mineral., vol. 20, p. 609–630.

Irving, E. M. (1935) *Geology of a portion of the Corona and Riverside quadrangles, California*, Thesis for Master's degree, Univ. Calif. at L. A. (unpublished).

Jenkins, O. P. (1938) *Geologic map of California*, Calif. Div. Mines.

Kelley, V. C., and Soske, J. L. (1936) *Origin of the Salton volcanic domes, Salton Sea, California*, Jour. Geol., vol. 44, p. 496–509.

Kew, W. S. W. (1924) *Geology and oil resources of a part of Los Angeles and Ventura counties*, U. S. Geol. Survey, Bull. 753.

King, R. E. (1939) *Geological reconnaissance in northern Sierra Madre Occidental of Mexico*, Geol. Soc. Am., Bull., vol. 50, p. 1625–1722.

Knopf, A. (1929) *The Mother Lode system of California*, U. S. Geol. Survey, Prof. Paper 157.

Larsen, E. S. (1935) *Geologic map of the San Luis Rey, Corona (in part), and Elsinore quadrangles*, U. S. Geol. Survey (unpublished).

——— (1941) *The batholith of Southern California*, Science, vol. 93, p. 442–443.

Mendenhall, W. C. (1910) *Notes on the geology of Carrizo Mountain and vicinity, San Diego County, California*, Jour. Geol., vol. 18, p. 336–355.

——— (1912) *in* Willis B., *Index to the stratigraphy of North America*, U. S. Geol. Survey, Prof. Paper 71, p. 505–506.

Merriam, R. H. (1941) *A southern California ring dike*, Am. Jour. Sci., vol. 239, p. 365–371.

Merrill, F. J. H. (1914) *Geology and mineral resources of San Diego and Imperial counties*, Calif. State Min. Bur., State Mineral., Bienn. Rept., 1913–1914, p. 1–113.

Miller, F. S. (1937) *Petrology of the San Marcos gabbro, southern California*, Geol. Soc. Am., Bull., vol. 48, p. 1397–1426.

Miller, W. J. (1926) *Red Rock Canyon, California*, Jour. Geog., vol. 25, pp. 330–336.

——— (1931) *Geologic sections across the southern Sierra Nevada of California*, Univ. Calif. Publ., Dept. Geol. Sci., vol. 20, p. 331–360.

——— (1933) *A comparison of two granites* (abstract), Geol. Soc. Am., Bull., vol. 43, p. 161–162.

——— (1934) *Geology of the western San Gabriel Mountains of California*, Univ. Calif. at L. A. Publ., Math. and Phys. Sci., vol. 1, p. 1–113.

——— (1935a) *A geologic section across the southern Peninsular Range of California*, Calif. Jour. Mines Geol., State Mineral., Rept. 31, p. 115–142.

——— (1935b) *Geomorphology of the southern Peninsular Range of California*, Geol. Soc. Am., Bull., vol 46, p. 1535–1562.

——— (1938) *Pre-Cambrian and associated rocks near Twenty-nine Palms, California*, Geol. Soc. Am., Bull., vol. 49, p. 417–446.

——— (1940 *Some features of faulting in Southern California*, Jour. Geol., vol. 48, p. 385–420.

——— (1944a) *Geology of Palm Springs-Blythe Strip, Riverside County, California*, Calif. Jour. Mines Geol., State Mineral. Rept. 40, p. 11–72.

——— (1944b) *Geology of parts of the Barstow quadrangle, San Bernardino County, California*, Calif. Jour. Mines Geol., State Mineral. Rept. 40, p. 73–112.

——— (1944c) *Geology of the Needles-Goffs region, San Bernardino County, California*, Calif. Jour. Mines Geol., State Mineral., Rept. 40, p. 113–129.

——— (1945) *Observations on pseudo-dikes and foliated dikes*, Jour. Geol., vol. 53, p. 175–190.

——— and Webb. R. W. (1940) *Descriptive geology of the Kernville quadrangle, California*, Calif. Jour. Mines Geol., State Mineral., Rept. 36, p. 343–378.

Murphy, F. M. (1932) *Geology of a part of the Panamint Range, California*, Calif. State Mineral., Rept. 28, p. 329–356.

Noble, L. F. (1932a) *Excursion to the San Andreas fault and Cajon Pass*, 16th Intern. Geol. Cong., Guidebook 15, p. 10–21.

——— (1932b) *The San Andreas rift in southeastern California*, Carnegie Inst. Washington, Year Book 31, p. 355–363.

——— (1941) *Structural features of the Virgin Spring area, Death Valley, California*, Geol. Soc. Am., Bull., vol. 52, p. 941–999.

Nolan, T. B. (1943) *The Basin and Range Province in Utah, Nevada and California*, U. S. Geol. Survey, Prof. Paper 197-D, p. 141–196.

Oakeshott, G. B. (1937) *Geology and mineral deposits of the western San Gabriel Mountains, Los Angeles County*, Calif. Jour. Mines Geol., State Mineral., Rept. 33, p. 215–249.

Osborn, E. F. (1939) *Structural petrology of the Val Verde tonalite, southern California*, Geol. Soc. Am., Bull., vol. 50, p. 921–950.

Pack, R. W. (1914) *Reconnaissance of the Barstow-Kramer region, California*, U. S. Geol. Survey, Bull. 541, p. 141–154.

Sampson, R. J., and Tucker, W. B. (1942) *Mineral resources of Imperial County*, Calif. Jour. Mines Geol., State Mineral., Rept. 38, p. 105–145.

Simpson, E. C. (1934) *Geology and mineral deposits of the Elizabeth Lake quadrangle, California*, Calif. Jour. Mines Geol., State Mineral., Rept. 30, p. 371–415.

Smith, J. P. (1904) *The comparative stratigraphy of the marine Trias of western North America*, Calif. Acad. Sci., Pr. 3, Geol. 1, p. 323–430.

Soper, E. K. (1938) *Geology of the central Santa Monica Mountains*, Calif. Jour. Mines Geol., State Mineral., Rept. 34, p. 131–180.

Taliaferro, N. L. (1942) *Geologic history and correlation of the Jurassic of southwestern Oregon and California*, Geol. Soc. Am., Bull., vol. 53, p. 71–112.

Thompson, D. G. (1929) *The Mohave Desert region, California*, U. S. Geol. Survey, W.-S. Paper 578.

Trask, P. D. (1926) *Geology of Point Sur quadrangle, California*, Univ. Calif. Publ., Dept. Geol. Sci., vol. 16, p. 119–186.

Tucker, W. B., and Sampson, R. J. (1943) *Mineral resources of San Bernardino County*, Calif. Jour. Mines Geol., State Mineral., Rept. 39, p. 534–535.

Vaughan, F. E. (1922) *Geology of the San Bernardino Mountains north of San Gorgonio Pass, California*, Univ. Calif. Publ., Dept. Geol. Sci., vol. 13, p. 319–411.

Webb, R. W. (1932) *Geology of the eastern Sierra Pelona Ridge and vicinity*, Thesis for Master's degree, Calif. Inst. Technology (unpublished).

——— (1938) *Petrography of Los Angeles syenites*, Pan-Am. Geol., vol. 49, p. 166–168.

——— (1939) *Evidence of the age of a crystalline limestone in southern California*, Jour. Geol., vol. 47, p. 198–201.

Woodford, A. O. (1943) *Crestmore minerals*, Calif. Jour. Mines Geol., State Mineral., Rept. 39, p. 333–365.

———, and Harriss, T. F. (1928) *Geology of Blackhawk Canyon, San Bernardino Mountains, California*, Univ. Calif. Publ., Dept. Geol. Sci., vol. 17, p. 265–304.

——— (1938) *Geological reconnaissance across Sierra San Pedro Martir, Baja California*, Geol. Soc. Am., Bull., vol. 49, p. 1297–1336.

———, Crippen, R. A., and Garner, K. B. (1941) *Section across Commercial quarry, Crestmore, California*, Am. Mineral., vol. 26, p. 351–382.

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BOOKS—WAR VICTIMS

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Library of Congress, Washington 25, D. C.

During the war, the libraries of half the world were destroyed in the fires of battle and in the fires of hate and fanaticism. Where they were spared physical damage, they were impoverished by isolation. There is an urgent need—now—for the printed materials which are basic to the reconstruction of devastated areas and which can help to remove the intellectual blackout of Europe and the Orient.

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